PERSPECTIVES ON LAND MODELLING

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Edited by

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PREFACE

During the last two decades, government and private efforts to gather land resource data have been extensive. The challenge now lies in making effective use of these data to develop sound management strategies and effectively plan the use of Canada's natural resources. Modelling constitutes one technique which is increasingly being used to integrate various data components (e.g., land quality, quantity, use, economics, etc.), to examine future trends and possibilities, to fill specific information gaps, and to provide us with a better understanding of what is happening to the land resource base.

On November 17-20, 1986, groups and individuals from Canada and the United States attended an interdisciplinary workshop which aimed to explore, for the first time, how models can enhance our understanding of the land resource and our ability to influence it. This workshop, sponsored by the Canada Committee on Ecological Land Classification (CCELC), was a result of a recommendation made at the third national meeting of the CCELC in May 1983. At this meeting, the consensus was that the CCELC should focus more on the interpretation and application of ecological data and that more of an attempt should be made to present applications of the results of Ecological Land Survey (ELS), rather than the ELS approach itself.

The primary goals of this workshop were to facilitate an exchange of information on the use of land modelling and the development of new modelling techniques, and to review progress in the field to date. A vast array of representatives was on hand to discuss current land modelling initiatives, methods, and results. Plenary sessions during the workshop covered a wide range of topics. A series of presentations in a session entitled *Models in Land Resource Planning and Management* stressed an integrated modelling approach (e.g., multiresource modelling). Presentations in the *Modelling the Effects of Climate Change on the Land Resource Base* session tended to focus on the future trends and possibilities while some

presentations in the *Models for Acid Deposition Impact Assessment* session demonstrated how models can be used to fill information gaps and help understand what is happening. Other sessions included: *Using Temporal and Spatial Models for Natural Resource Management*; a poster session on *Land Modelling Applications* and a work session on *Priority Issues, Methods, and Applications* which further encouraged one on one and small group discussions amongst the participants.

Selected contributions to the workshop were compiled and edited in this volume. Ron Gélinas compiled the papers and conducted scientific and technical review. Further review, detailed editing and production were undertaken by Deborah Bond and Barry Smit.

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PART 1
BACKGROUND PAPERS

1

MODELS AND THE DECISION MAKER

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INTRODUCTION

Any attempt to discuss the overall field of land modelling is a formidable task simply because the term "modelling" and the word model have been so ill-used and abused as to become almost worthless. Modelling appears to apply to almost anything unreal which reports to be something like reality. It therefore encompasses a very wide range of analytical techniques and procedures for social sciences, physical sciences, political sciences through to simple logical use of analogy that we each use on a day to day basis in our own lives. When applied to land and to its use it therefore encompasses everything about land, its users and its function. Because land is a common resource it is influenced by the demands of all sectors, and its myriad characteristics can all contribute to some form of modelling exercise.

We all carry mental models which we apply when we see something as simple as a doorknob knowing that that shape means turn and we anticipate that that will indeed open the door. In fact the whole process of modelling should, if it is applied properly be precisely that -- a means of opening doors, of adding to our appreciation of the functions of reality. The purpose of the use of models for land is to make a positive contribution to how land is used, planned and managed, all of this done in support of Canada's broader social, economic and environmental goals. But to be effective in doing such, it must fit properly into the broader context. Therefore I put forward at this point my personal model of the land universe. It is based on a number of premises:

1. that what scientists do is to serve the decision process either directly or indirectly in order to influence decisions,
2. that problems are what powers the research priorities with respect to land -- that that which is seen to be politically or publicly essential to solve establishes priority, and
3. that overall sustainability of life, production or environment is the ultimate goal of why we deal with land. Our efforts are therefore directed at bringing information to the decision process--and most particularly to the urgent priorities of society -- in order that the management planning and use of our land resource occurs in a more sustainable fashion.

The reason therefore that we model is because it helps us to achieve this. We undertake simple or complex modelling procedures because they aid us to:

1. understand better what is happening (e.g., descriptive models),
2. fill specific information gaps (e.g., interpolate, extrapolate, forecast, predict),

3. demonstrate our understanding more effectively, or
4. exert influence on the decisions of others.

Models are useful and necessary only if they aid us in doing these things. Unfortunately, modellers sometimes forget these factors. Thus we have many models lying in desk drawers, on shelves or gathering dust in libraries which do none of these and in fact may even obscure understanding. Here I turn to a simple example to show you how, in a very practical sense the abuse and misuse of some key analytical and modelling procedures can thwart our objectives in ensuring that some degree of wisdom is applied to the decision process with respect to land. It also illustrates that indeed we are the captives of our own models and that some models exert an immense influence on the way in which our overall society is run and managed.

DIVINING TRUTH

Once upon a time a prince was faced with some vexing problems. Should he expand the moat at the expense of the adjoining village? Was it wise to burn down the forest and create new pastures? Should his precious treasuries be used to pay for the repair of the irrigation system? Perplexed by these complex decisions, the prince called for his faithful wizard. With great ceremony, a chicken was slaughtered and the answers were divined from the entrails. The moat augured well. Burning of the forest was fraught with peril and the gods favoured repair of the irrigation works. Thus the prince, reassured by the expertise of his principal advisor, could proceed confident that he was doing the right thing. The model had helped the prince to derive truth from the unknown.

Nowadays of course we are much more modern. We no longer believe that type of mumbo-jumbo, and chickens may live long and healthy lives far from the prediction process. The modern official does not believe in rites and incantations. Instead he turns to an advisor schooled in economics, in engineering or computer science. When faced with a seemingly irresolvable problem, he has modern techniques to assist him in divining truth . . . But to a great extent I would suggest that the net result has changed little. While the soothsayer may have been replaced by a scientist, the liturgy is now chanted in numbers. The entrails have been replaced by a complicated model and the ritual has been replaced by a feasibility study.

As in medieval times, the official seldom understands what he is given. The advisor has the power of choice, but no responsibility. Often the numbers crunched to provide an answer to the unanswerable have as much or less relevance to the real social, economic and environmental problems as the configuration of the entrails did in medieval times. And in like fashion, non-believers can be excommunicated as heretics for espousing the "uneconomic". These are unfortunate similarities which pervade the provision of advice to those who must make complicated decisions affecting the future, the environment and society.

While the parallel put forward in the preceding paragraphs may be laughable, it is regrettably real and has real human and environmental consequences. The salient points are:

1. an analogue model is put forward which supposedly simulates reality either in entrails or in numbers and which calls for particular actions,
2. the ultimate decision maker is generally unable to understand, question or challenge the inner workings of the model, and
3. if the predicted does not come true it was because the prince was not devout enough -- he did not follow instructions adequately and not through any fault in the model.

One particular incantation which has received political currency which far exceeds its real relevance or utility is benefit/cost analysis. It has become the liturgy for an entire

generation of decision makers -- the public profession of a faith to the "economic" and therefore implied rational spending of public monies. But this most common of tests for project proposals and decisions is usually misapplied. It is a model which is often used to address entirely the wrong questions, and even if done properly is usually ill-suited to the types of decisions politicians must really make. It is becoming increasingly clear that just as in the long run the entrails often failed to provide clear paths to enlightened and lasting decisions, so are the current practices of benefit/cost. Yet such is the strength of the myth surrounding this particular analytical procedure that it will be extremely difficult to dislodge it as a touch-stone. It is a model which is usually used outside the frame of reference for which it was designed and which is used as a model for social goals whereas in fact it is suited only to private benefit analysis. Like many other models, it has the appearance of providing simple answers to complex questions. While it is a useful tool to raise questions or to identify sensitivities, it is much less useful as a tool in the evaluation of real social choices for land use. It favours the short term and it favours the individual. While it answers the question "is it economic?" in a very simplistic manner (often satisfying to the politician) it does not answer the questions of "is it socially acceptable?", "is it politically suicidal?", "is it environmentally sustainable?", or "is it logical and practical?".

What models like this can do is force us into a *reductio ad absurdum*; where a vast range of complex social, economic, political and environmental factors can be reduced to a seemingly simple, often single digit answer. While most practitioners realize the drawbacks (the problems with all of the assumptions which have gone into the model) the politician or user often does not and is satisfied in this economic model with simply the answer to the question "does it have greater than a one-to-one benefit/cost ratio?" No matter what the answer, he has essentially been baffled by entrails. As a consequence of over-simplification, he has been deceived into thinking that he is making a defendable, logical and objective decision. What has in fact happened is he has made a subjective, and broad-ranging decision with no real appreciation of the assumptions or of the impacts of that decision.

Why does this misuse of models occur? Perhaps the answer lies in the fundamental differences between science and government, deriving from their different objectives and therefore ways of viewing the world. Alistair Crerar, from the Environment Council of Alberta has identified some of these differences (Table 1.1).

The existence of these, almost opposing characteristics make it very difficult for scientists and politician/bureaucrats to communicate with each other. Little is shared -- either jargon or attitude. The political decision maker is virtually forced to use results in a deterministic way -- to be selective, to simplify, then execute his decision. He will make a decision with, or without the scientific contribution. We must accept this, and tailor our results so that they feed the decision process and minimize potential for misuse. Perhaps models, like cigarette packages should come with warnings of possible dangers to users.

IS THERE A MORAL?

The key to the use of models is to define clearly the need or demand which they are designed to serve. A good model must indeed serve -- that is it must not confuse. Users must take care not to over-simplify particularly through hiding key variables which are important, and the model ultimately must bring added insight -- value added to a decision process. Models must also stand the test of logic. Unfortunately, models sometimes take on lives of their own -- particularly if they have become entrenched, institutionalized and used as points of reference. Through simple electronic or mechanical attraction, they can capture practitioners and absorb them in internal fine-tuning or esoteric development while losing sight of the overall and broader objectives for which

TABLE 1.1: CHARACTERISTICS OF SCIENCE AND GOVERNMENT

SCIENCE	GOVERNMENT
Probability accepted	Certainty desired
Inequality is a fact	Equality essential
Anticipatory	Time ends at next election
Flexibility	Rigidity
Problem oriented	Service oriented
Discovery oriented	Mission oriented
Failure accepted and utilized	Failure intolerable
Innovation prized	Innovation suspect
Veneration for facts	Facts are material to support desired conclusion
Innate caution to accept new conclusions	If theory or proposal is popular with electorate it is correct
Replication essential for belief	Beliefs are situational
Clientele diffuse diverse or not even present	Clientele specific, immediate and insistent

Source: Crerar (1986)

the model was initially intended. Some practitioners of political and economic models have been absorbed by their models to the extent where they work to change reality to match their model, even when shown that the model does not fit reality and in fact is not logical and functional. (Followers of Karl Marx are a case in point). In fact, often the more simple (another term is elegant) models are the most effective simply because they are understandable and many of the users are able to comprehend precisely how they work and why they get the results which they do. But models are critical to the land decision process. Unlike some branches of science, we cannot experiment -- our decisions involve the real universe. Models help us test our hypotheses without placing the real people, resources or ecosystems at risk. Non-viable options can be screened out, hopefully protecting us from many costly errors.

While I have regaled you with a list of concerns and caveats with respect to modelling, taken together these do give us some indications of where there is a real need for modelling to serve particular needs with respect to land resource management in this country. I put forward as a partial list the following categories of need where models can probably be of optimum assistance:

1. to analyze supply relative to demand at national or regional levels,
2. to project future scenarios (i.e., new demands such as biomass production for fuels),
3. to extrapolate from known information to cover broader national or regional areas,
4. to simulate changes in major economic, natural or policy variables which could influence land capability, quality, supply or demand (e.g., acid rain, free trade),
5. to examine the potential impacts of new technologies (e.g., productivity increases, new advances in transport technology),
6. to aid in risk management (flood, fire, acid rain), and
7. to aid directly in the physical planning process at local and regional levels

(e.g., simulation, expert systems, etc.).

Some means of dealing with these types of questions is critical in our ability to build towards a means of managing our land base in a sustainable fashion. Herein lies the challenge -- to those of you who are doing modelling to continue to develop quick, simple, reliable and understandable means for addressing these questions.

REFERENCES

Crerar, A. 1986. Presentation to the Science Council Meetings on Water Policy, Ottawa, November 5, 1986.

2

THE CRITICAL ROLE OF SCALING IN LAND MODELLING

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ABSTRACT

The distinguishing feature of land modelling is its focus on spatial contiguity as an organizing principle. Primary human experience is in a spatial matrix, and things that are tangible have a significant spatial component to them. Therefore, land modelling involves distinctly tangible material. This has its advantages, but also its drawbacks. The principal cost of this tangibility is an over commitment to the level at which the observer has his tangible experience. This leads to inappropriate scaling in two important ways. First, there are other levels at which data might be collected and problems may be analyzed. Second, and more problematically, there is the temptation to force the devices that pertain to the level of the tangible to higher levels at which the land modelling proceeds. At the very least, forcing tangibility to too high a level means extra bookkeeping. Worse, the land modelling effort can be thwarted by the accumulation of rounding error that leads to concretely wrong results or fragile models.

The robust FORET forest stand simulator of Shugart and West (1979) generates tree data that would come from an area of approximately one twelfth of a hectare. The model is realistic and transferable to many forest types by simple changes in growth and death functions. The dynamics of the model show gap phase replacement, wherein one tree comes to dominate the plot until it dies and is replaced. Although it models vegetation over the very tangible area a woodsman would experience sitting on a stump, and it keeps track of individual stems, the model does not function spatially in a tangible fashion. It reports which stems are what size, but it explicitly excludes spatial placement of trees. What it does use are the principle processes whereby trees grow and interrelate; height above the ground is critical whereas details of where in the stand a stem is rooted are unimportant. The context is provided to the model by data from range maps which parameterize the tree species, and the working relationships inside the model come from the intuition and common knowledge of forest managers and field experience. The model works so well because it is scaled to the level of organization of the questions it addresses, and not to the scale of the tangible experience in a forest glade. Land modelling can only be effective if the modeller is explicit about the questions that the model is built to address, and if the intrusion of all other levels of analysis into the model is minimal.

INTRODUCTION

The larger scale ecological entities that define the upper levels of ecology may be divided into three types: communities, defined by type of organism; ecosystems,

defined by processes, fluxes and mass balances; and landscapes, defined by spatial contiguity. Various ecological studies may amount to mixtures of these three classes of investigation. Land modelling can involve all three, but usually there is an emphasis on spatial contiguity as an organizing principle. Primary human experience is in a spatial matrix, and things tangible have a significant spatial component to them. Therefore, land modelling involves distinctly tangible material. Of the three classes, communities, ecosystems or landscapes, the last is focussed on the most tangible objects. One can see a landscape more easily than a floristic composition or nutrient flux.

TANGIBILITY OF LANDSCAPES

Tangibility is often a matter of scale. At some levels, ecology studies aspects of nature that tend to be tangible, like trees, lakes or animals. Entities scaled much larger than ourselves are often difficult to experience directly, unless we rescale our observation protocol. Note the striking change in scale of perception that is forced on an airplane passenger in the few seconds between clearance for takeoff at the beginning of the runway and the first turn at a thousand or so feet. In situations where we do have direct experience of large-scale ecological entities, spatial mapping often plays a crucial role.

Prediction is a determinant of human action; if it worked before we do it again. This is involved in Herbert Simon's principle of satisficing -- a businessman does not make the optimal decision, but rather the first satisfactory one to come along, and that is usually what he did last time (March, 1978). In casual experience we readily presume that if something happened according to expectation, then that way of viewing the world captured some aspect of reality. The predictive aspects of science are often taken, albeit mistakenly, as indications that good scientific models are true above and beyond what is observable. The world of primary human experience seems so real because, as biological entities, we need to be able to commit ourselves to certain courses of action. When we follow a course of action, we do so with the presumption that the model behind the decision to act is predictive. Usually we are not surprised.

There is, therefore, a certain commitment to tangibles because of their predictive power. This predictive characteristic of tangibles comes from their surfaces having high dimensionality -- that is, they can be viewed using many criteria, and yet their surfaces appear in about the same place, despite the change in observation protocol (Allen et al., 1984). For a tangible, a definition of the object based on one way of looking at it can be translated with effect to another set of considerations. Science is interested in that which is robust to transformation of observational criteria. Indeed, that is the source of scientific generalizations. Tangible things are a subset of those things which are robust to transformation. They appear real because they are predictive.

The tangibility of spatially arrayed study material generally engenders prediction. Therefore, tangibility is a friend to the land modeller. Nevertheless, that friendship is not constant. The price for the tangibility of forest stands or landscapes is the constant danger of a commitment to those tangibles beyond their usefulness. The tangibility of spatial maps is seductive. The feeling that they are real leads to a reluctance to abandon them when they do not apply. Tangibles are level specific, and so if the scientific question that the land modeller probes belongs to a different level of organization, then the modeller must specify his system with new entities belonging to the pertinent level (Allen et al., 1984). In casual experience, like that of the airplane passenger during takeoff, we have a remarkable capacity for intuitive rescaling, but that intuition does not always serve the scientist. The airplane passenger is passive and yields to his context, while the scientist hopes to manipulate that context actively. The appeal of tangibles to

the land modeller's intuition may lock him into a frame of reference more local than he would prefer.

RESCALING IN THE FACE OF ERROR

If it were always obvious when the system had been inappropriately specified, then the modeller could wait for the warning signals and respecify before much damage had been done. Unfortunately, inappropriate scaling of the model system often leads to a general failure of explanation, the source of which is not obvious.

Consider a very simple system conceived at the wrong level. Children sometimes ask why a mirror switches the image left right but not up down. The question arises from a confusion of levels, a switching of logical types (Bateson, 1980). Although up and down involve relative directions as do left and right, left and right are an endogenous self-reference while up and down consider the image relative to its setting. When a man stands on his head so that his feet and not his head point up, his left hand remains his left hand because left is a reference to self. The reference to self alone represents a lower level of organization than the consideration of the thing in relation to its context. The switch of left to right between the thing and its mirror image occurs only so long as the thing and its image are both viewed as autonomous and separate. If we emphasize that the thing, the mirror and the image are all parts of one system, then we have moved up a level. Now we note that the top of the thing is directly across from the top of the image, exactly in the manner that the left hand of the image is directly opposite the right hand of the thing; there is no switch. If the situation can become subtly confused in such a simple case as a mirror image, then errors in specification of level in complex land models could easily lead to unfathomable failures of prediction.

Inappropriate scaling limits the land modeller in two important ways. First, there are other levels at which data could be collected and problems could be analyzed, and these levels may be unwittingly ignored. Second, and more problematically, there is the temptation to force the devices that pertain to the level of the tangible to the higher levels where the land modelling should proceed. At the very least, forcing tangibility to too high a level means extra bookkeeping. Worse, the land modelling effort can be thwarted by the accumulation of rounding error that leads to concretely wrong results or fragile models. A painful example of the rounding error problem arose during the modelling effort of the Grasslands Biome, of the American International Biological Program. The large model was programmed to update all compartments on the same small time increment. The model worked reasonably for a period of simulated time. That time period is what is reported in Bledsoe et al. (1977). However, the decomposition term was minutely too small. As a result, due to rounding error alone, the model eventually made a succinct statement on the cost of inappropriate scaling, it covered the Great Plains with several feet of buffalo dung (Allen and Starr, 1982). Different processes operate at different rates, and simulation of them should reflect those different rates by using an appropriate array of time increments for system update.

APPROPRIATE SCALING

When a model works exceptionally well with great generality, it is worth looking at it to see what, in particular, was done correctly. The robust FORET forest stand simulator of Shugart and West (1979) generates tree data that would come from an area of approximately one twelfth of a hectare. The model is realistic and transferable to many forest types by simple changes in growth and death functions. The dynamics of the model show gap phase replacement, wherein one tree comes to dominate the plot until it dies and is replaced. Although it models vegetation over the very tangible area a woodsman would experience sitting on a stump, and it

keeps track of individual stems, the model does not function spatially in a tangible fashion.

When Shugart presents the model at professional meetings, there are two well meaning but misguided suggestions that come from the floor. Often a physiologically inclined ecologist will stand and complain that there is not any explicit physiology in the model. The claim is that somehow things would be improved if leaf resistances or explicit photosynthetic parameters were included. The second well-intended suggestion asks that, since the model keeps track of individual stems, it should also keep track of where in the stand they are, and act upon that information to refine the shading effects. Both these proposed modifications are at best irrelevant and at worst would destroy the model's dynamics if they did have an effect. Signals almost always either attenuate or amplify; a signal persists at the same amplitude only if very explicitly designed controllers are in place, as in the telephone system. Both physiology and explicit spatial placement of trees would probably be irrelevant, and so would only amount to cumbersome extra bookkeeping. If steps were taken to preserve physiological or horizontal spacing effects through the functioning of the model over extended simulated time, then the respective signals would amplify to the detriment of model performance. The model would either freeze up or blow up.

Correct scaling demands proposing entities that are bound by the appropriate surfaces. Surfaces are a reflection of closure of loops of processes. Things inside the surface are strongly interrelated, while things across the surface are connected by weak processes. Shugart's model explicitly excludes spatial placement of trees with good reason. The spatial placement of trees does not correspond to any process that integrates the forest to give the emergent behaviour. Therefore, where trees are rooted is at best irrelevant. What the model does use are the principle processes whereby trees grow and interrelate; height above the ground is critical for an understanding of survivorship. The trees are modelled as autonomous users of the light resource, but are also modelled as contributors to group shading effects for all smaller trees. The overstory and understory are implicitly uncoupled by the difference between the way trees are modelled when looking up as opposed to down. The context is provided to the model by range map data which parameterize the tree species. The working relationships between trees and the stand come from the intuition and common knowledge of forest managers and field men. Shugart and West built the model to generate exactly the sort of data that those field workers might collect. The model works so well because it is scaled to the level of organization of the questions it addresses, and not to the scale of the tangible experience in a forest glade. From FORET, the land modeller can learn that he will only be effective if he is explicit about the questions that the model is built to address. The intrusion of all other levels of analysis into the model must be minimal.

It would be possible to model questions that pertain to tree physiology with a model scaled to that level. One could also model a small site using a map of trees growing in particular places. The important thing to remember is that either of those models is scaled for a particular purpose. The FORET model is scaled to give stand integration, an important aspect of land modelling, but not one which maps onto primary human experience. While land modellers can do well to model at the level of tangible experience, they must also be prepared to model at levels which are intangible. While models for tangible landscapes might be one of the desired end products, land modellers must be prepared to do some critical calculations using intangible abstractions. For example, the Great Lakes are tangible from satellite images, but deposition of pesticides into them, a pertinent land modelling question, is not tangible. By calculating with appropriate abstractions like air masses, and identifying the pertinent processes, the land modeller can infer deposition correctly. The time is

now for a process-oriented approach to land modelling (Allen and Starr, 1982; Allen et al., 1984). Just because we can see the land, we do not have to be limited by that experience.

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PART 2
MODELS IN LAND RESOURCE PLANNING AND MANAGEMENT

3

AN OVERVIEW OF THE SOUTHERN UNITED STATES MULTIRESOURCE MODELLING

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ABSTRACT

Quantifying the interactions among natural resources produced within a planning unit under current and future land management is an important step in the land management planning process. This paper presents a conceptual framework for assessing the impact of changing timber and land management activities on the resources of timber, forage, wildlife, fish, and water at the regional level. A commonly defined set of land base and timber management descriptors was developed to facilitate the integration of the single resource models. Individual models for timber, forage, wildlife, fish, and water were constructed at an appropriate scale for the production processes of each individual resource. Aggregation of the individual model outputs provides a consistent set of multiresource projections from the same land base. This conceptual framework was applied to the southern region of the United States to examine the impact of timber management and land-use shifts.

INTRODUCTION

Integrated multiple resource analyses for natural resource management planning require an understanding of the ecological and economic processes operating within the environmental system at several temporal and spatial scales. The complexity in developing a common conceptual framework to address questions regarding land management actions is evidenced by the number of different approaches that have been developed to quantify the impacts of land management activities on resource production (Hirst, 1984; Hollings, 1978). Projections of resource interactions require repeatable and definable procedures for quantifying multiple resource responses to changing land management actions. This desire for objectivity has been the reason for the development of mathematical models (Hollick, 1981). The underlying assumptions about resource interactions within the environmental system must be made explicit.

Planning by the Forest Service (FS) is required at the local level for national forests and at the national level for the country as a whole. A periodic assessment of the renewable resources produced on all forest and rangeland of the United States is required of the FS by the Forest and Rangeland Renewable Resources Planning Act of 1974[1] and the National Forest Management Act of 1976.[2]

The national assessment is a technical statement of the status and trends of renewable natural resources. Tasks specified in the Renewable Resources Planning Act (RPA) have been interpreted (Hoekstra and Hof,

1985) to require the following information:

1. a summary of the current and historical production and consumption of resources: timber, forage, recreation, wildlife, and water,
2. a projection of future multiresource production and consumption patterns from the current situation, and
3. an analysis of opportunities for improving the future resource production and consumption situation, considering trade-offs in the production and consumption of all renewable resources.

Tasks 2 and 3 require analytical tools which quantify the ecological and the economic processes of the environmental system so that futures based on alternative assumptions about resource availability, economic production, and economic demands can be examined. Resource projections in previous assessments have been accomplished by focussing on each resource separately, thus ignoring multiple resource interactions, or by focussing on resource interactions in isolation of the single resource projections (United States Department of Agriculture [USDA], Forest Service, 1976 and 1980).

Multiresource production at the national scale was examined using a large linear programming (LP) model, NIMRUM (Ashton et al., 1980). The ecological production estimates within the resource systems were derived using an interdisciplinary (ID) team. Acres of land in the entire forest and rangeland base of the United States were allocated by ownership to different management strategies based on the decision criterion of minimum cost. Because of the large size of this model, analytical runs were limited, reducing its utility. ID teams are a viable alternative to generate uniform data at the national level; however, the method and the resultant data are subjective (Mitchell and Pickens, 1985). Furthermore, the information is not easily updated.

This paper presents the conceptual framework for integrating resource models projecting likely futures for timber, forage, wildlife, fish, and water at the regional level. Models recently developed for forage (Joyce, 1988), wildlife (Flather, 1988), fish (Flebbe, 1988) and water (Sisler, 1986), were applied to the southern region of the United States. Two additional models, the timber inventory projection model (Timber Resource Inventory Model [TRIM]) (Tedder et al., 1987), and the land area projection model (Alig, 1986), are briefly described in this paper as components of the multiresource framework. This case study was designed to examine the effect of land-use and timber management changes on forage production, wildlife abundance and occurrence, fish abundance, and water yield within the southern United States.

REGIONAL MODEL FRAMEWORK

Several basic concepts were used in developing our multiresource framework. Subnational analysis and reporting boundaries may be delineated by ecological, economic and political factors. Resource production within ecosystems will be impacted primarily by a set of factors specific to a region. The mix of resources produced within a smaller, regional geographic area are more similar than across the nation as a whole (e.g., timber, water yield, forage, and white-tailed deer in forested environments as compared with corn, water yield, forage, and white-tailed deer in agricultural environments). An integrated framework should contain a combination of basic environmental and economic factors that affect likely future resource production.

The theoretical dynamics of ecological resource interactions are poorly understood, and the availability of resource information in national and regional inventories has limited the development of such theory and quantitative descriptions (Joyce and Hoekstra, 1984; Joyce et al., 1983). Resources have been modelled using a set of common production factors within a region. However, the more complex connections and feedbacks between individual resource models at the regional level have not been accomplished in models which combine economic and ecological factors.

The conceptual framework we developed integrates single resource models that estimate the effect of changing land use and timber management on forage, wildlife, fish, and water (Figure 3.1). Natural resource systems are dynamic in that management for one resource affects a second resource which may, in turn, affect the first resource. These secondary feedbacks are in some cases, subtle, and in most cases, not quantified. The development of truly multiresource interaction models awaits a clearer understanding of these resource responses to management (Joyce et al., 1983). As a first step toward the goal of projecting resource interactions, regional resource models can be designed to share common environmental factors that are influenced by timber and land-use management. These two management actions, among other factors, affect the production of natural resources including timber, forage, wildlife, fish, and water, and this effect can be quantified.

Land-use shifts will occur over time in any region. In the southern region, competition for land for commercial forestry and for agriculture has been projected (Alig, 1984). Commercial forestland and agricultural land not only produce timber and crop outputs, but are important habitat for a variety of wildlife species. In addition, southern forests are seen as a valuable potential grazing resource for livestock. Forestland and agricultural land management have an impact on water yield and levels of nutrients in streams and on fish habitat. Thus, the resource outputs to be projected include area and volume for softwood and hardwood, density of white-tailed deer, turkey, and occurrence of red-cockaded woodpecker, abundance of cold-water fish species, forage production, and water yield. The land area for the case study includes 12 states in the southern United States (Figure 3.2).

Land Base

The resources of timber, forage, wildlife, fish, and water are produced jointly from a common land base which has a variety of uses. Integration of inventory information about these resources was possible because a commonly defined list of land base and timber management descriptors was available for use in individual resource models. The integration of resources through a commonly defined set of variables is distinguished here from the integration of resource inventory information based on a common geographic area. Geographic integration of an inventory requires rules for defining system boundaries within which accurate estimates of joint production are possible. Although such ecological rules are being formulated (Allen et al., 1984), there is still uncertainty with regard to which system(s) joint production is usefully estimated within (e.g., communities, ecosystems, or landscapes).

The use of common variables for independent estimates of resource production frees the integrated analysis from the constraints of a common geographic base and permits estimates of multiresource interaction after the single resource analyses. Using aggregation rules to aggregate the results of all separate analyses to a common geographic area is less rigorous than the constraints of a common geographic base. These assembly rules for integration of analysis results can support reports for politically, ecologically, or economically defined geographic areas. We have used this method for integrating our resource models.

This discussion is not meant to suggest that a geographic basis for inventory does not contribute important information. To the contrary, it is the only way in which critical factors about the size, shape and distribution of resource interactions can be estimated. A combination of a predetermined geographic production system within which commonly defined variables are inventoried is ultimately needed to address the complete integration of resource production.

The common land base was constructed from Bureau of Census, FS Multiresource Inventories, and Soil Conservation Service (SCS) Natural Resource Inventory (NRI) data. The land-use/land cover types in the southern United States included the major categories

FIGURE 3.1: MULTIRESOURCE MODELS LINKED AT THE REGIONAL LEVEL

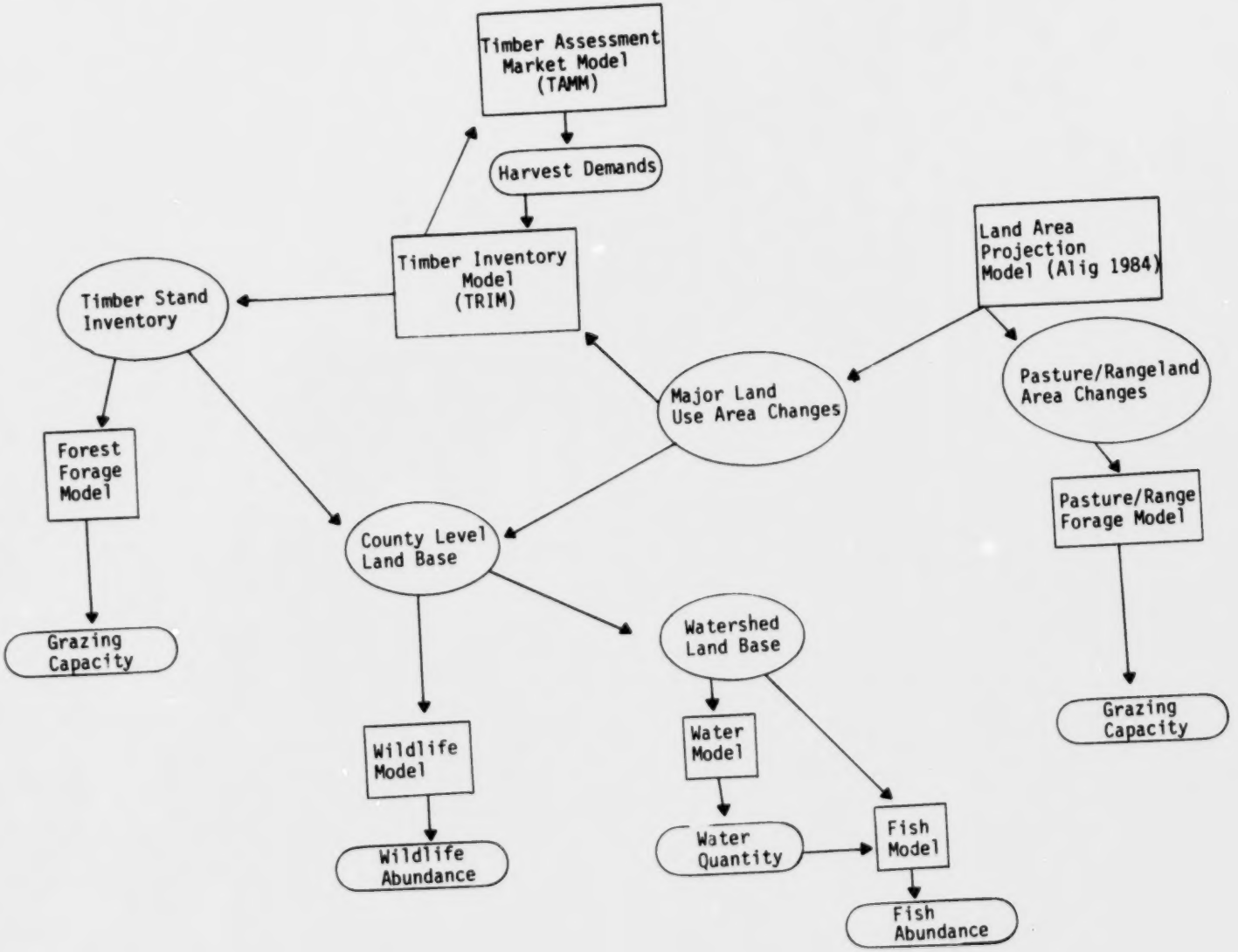
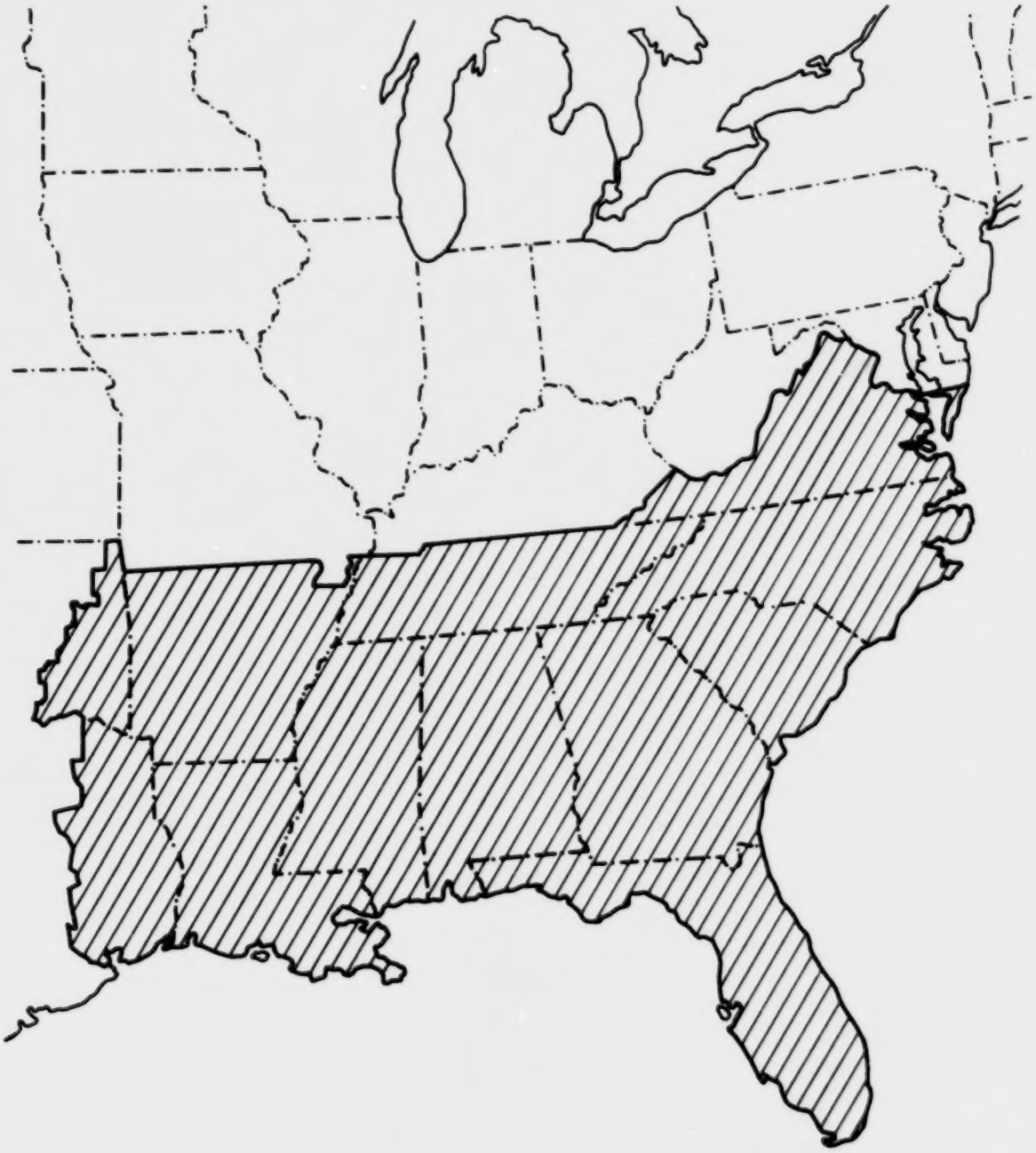


FIGURE 3.2: STUDY AREA IN SOUTHERN UNITED STATES



of forestland, rangeland, pastureland, cropland, urbanland, roads, and water. Data for commercial forestland, productive reserved forestland, and unproductive forestland were taken from the FS inventory on the assumption that FS data are the most detailed and accurate for these land types. Commercial forestland was further divided into five forest cover types: planted pine, natural pine, oak-pine, upland hardwoods, and bottomland hardwoods. The structure of each forest type was further described using age class, site class, stocking level, and timber volume. Data for cropland, rangeland, water, urbanland, and road areas were taken from the SCS NRI, on the assumption that SCS data are the most detailed and accurate for these land uses. Various aggregations of the land area data may be used within different resource models.

RESOURCE MODELS

Regional models did not exist for the resources of wildlife, forage, or fish. However, previous research indicated what kind of factors might be significant in the production of these resources at the regional level (Flather, 1988; Flebbe, 1988; Joyce, 1988). The specific variables to be projected as representative of the resources of timber, forage, wildlife, water and fish are: timber growing stock volume (merchantable volume), forage production in tons per acre, density classes or occurrence for individual wildlife species, water yield in terms of inches of runoff, and density classes of cold-water fish species groups.

Model development, structure and analysis for these resources are presented by others in this workshop: forage (Joyce, 1988, Chapter 4), wildlife (Flather, 1988, Chapter 5), fish (Flebbe, 1988, Chapter 6), and water (Sisler, 1986). Because the land area model (Alig, 1986) and timber model (Tedder et al., 1987) are used to drive changes in the land base, these models will be briefly described here.

Land Area Projection Model

Land area models can be single-resource oriented, in the sense that only one type of land use is projected, for example, forestland. Other land area shifts are assumed to be residual, and not contributing to these changes. This assumption fails in areas where competition for land use exists; for example, cropland, urbanland, and forestland in the southern United States are all projected to increase (Alig, 1984). Shifts in these other land uses must be projected if the entire land base is to be accurately taken into account. Land area changes over time dramatically affect the types of ecosystems available for resource production.

Forest acreage trends traditionally have been projected using expert opinion (Alig, 1986). More recently, the regional land area model, developed by Alig (1985) for the southern United States, uses economic variables, such as timber income, competing land use, and personal income, to project shifts within the major land-use/cover types and ownerships at the state level. These major land categories are: commercial forestland, pastureland and rangeland, cropland, and urbanland. Commercial forestland is divided by ownership: farmer, forest industry, and miscellaneous private. Projections for public land are based on information generated in public land management planning. In our framework, the land area model projects the shifts in the total land base, and these land area changes are used in the individual resource models.

Regional Timber Inventory Model

Only one regional timber model currently existed which met the ecological and economic criteria for our framework -- the regional timber resource inventory model (TRIM) (Tedder, 1983; Tedder et al., 1987). In this framework, timber management decisions and land area shifts between land cover types and land uses initiate changes in forage, wildlife, fish, and water production models.

The TRIM projects growing stock volume of timber within aggregated discontinuous homogeneous units of land defined by ownership, forest type, site class, and age classes.

The broad ownership categories include federal, farmer forest, non-industrial private, forest industry, and miscellaneous private. The forest types include planted pine, natural pine, oak-pine, upland hardwoods, and bottomland hardwoods. Empirical yield tables were developed for the five major forest types in the southeast (McClure and Knight, 1984). Output from the TRIM includes a 50 year projection of harvested volume and growing stock volume for softwood and hardwood by acre, ownership, forest type, site class and age class.

Timber is the only resource for which demand has been analyzed quantitatively at the national level. The Timber Assessment Market Model (TAMM) is an analytical tool used by the FS to project future levels of demand and supply of stumpage, lumber, and plywood from all forests in the United States (Adams and Haynes, 1980). Together, TAMM and TRIM form a modelling system which interacts to equilibrate supply and demand in the forest products sector. The demand for timber from one region can affect timber production in other regions. TAMM harvest requirements are provided to TRIM by 10 year increments. The harvest is allocated across the available timber inventory by TRIM and removed. Regeneration occurs for a predetermined portion of the harvested land and on land shifted into the timberland base from an unstocked category. Growth occurs on all forested land, and the new inventory is returned to TAMM. Stumpage price varies with the ability of the inventory to meet the demand in this equilibrium system.

ANALYSIS OF FUTURES

Likely futures are generated in this framework by projecting timber inventories or land area changes based on expected economic and social factors, and incorporating the timber inventory and land area changes into the projections for fish, forage, wildlife, and water. The major factors affecting resource production may be common across regions whereas the specific response of the resource to these factors will be unique within each region. Land-use/land cover changes will probably vary by region. Timber management changes on forestland affect the structure of these ecosystems further. Integrating either or both of these changes into the single resource models produces a consistent interpretation of the likely future multiresource supply.

Alternative futures are generated by changing the economic or social assumptions on which the timber and land area models are based. For example, human population projections could be varied and the land area model would produce a different set of projections for land use. These projections could, in turn, impact timber harvest, forage production, wildlife and fish abundance, and water yield.

Other projections could examine the impact of a significant decrease in timber growth, or in the area of forestland. The integrated framework allows the examination of the impacts of these scenarios on the production of forage, wildlife, fish, and water.

MODEL VALIDATION

Validation has been defined by various authors (Mihram, 1972; Van Horn, 1971) as any process which examines the correspondence between the model and the system under study. It is difficult to validate projection models in the way we normally think about validation because the system under study is the future. However, testing a model with historical data or data from other similar ecological systems increases our acceptance of the model as the projection tool, and our awareness of its weak points. Because ID teams have been used to generate the resource estimates, we have given ID teams the likely

future projections for timber and land area shifts, in order to test the validity of our results by comparison with the ID generated estimates. Such tests provide an intuitive test for the model results. Where possible (e.g., forage), we have compared the behaviour of our models with other data.

CONCLUSIONS

The conceptual framework presented in this paper integrates single resource models at the regional level to examine the impact of timber management and land area shifts on the production of the resources of timber, forage, wildlife, water, and fish. Within the framework presented here, the impact of regional demands for timber on the supply of other resources can be examined. Harvest demands from TAMM affect the forest stand structure and area in forestland in the TRIM which, in turn, affect the production of forage, wildlife, water, and fish in the individual resource models. Similarly, the impact of significant land area shifts on the regional resource production can be examined. Crucial to this framework is a land base description common to all resources. The reasonableness of timber inventory and land area projections will determine the reasonableness of the projections from the single resource models for forage, wildlife, water, and fish. The combined set of resource projections provides a consistently developed multiresource picture of the future supply of these resources. If applied to different regions, then the implementation of this conceptual framework must reflect the ecosystems and resources in the specific region.

The interaction of management for resources other than timber on multiresource production are impacts not presently included in these regional models. Clearly, forest cover dominates the ecological systems in the southern United States. Feedbacks from other resources to timber, or the management of those resources often mitigates the impact of timber on forage or wildlife. Resource planning seeks to quantify the effect of land management activities on the suite of resources produced within a planning unit. The objective of this multiresource analysis was to provide planners and policy makers an assessment of the possible impacts resulting from changes in land-use and timber management activities within a region. This effort to incorporate other resource considerations quantitatively into a single resource analysis represents the first generation of a multiresource analysis. This experience offers a structure from which future research activities can be recommended that will begin the process of incorporating the simplifying assumptions made in this analysis.

NOTES

1. Public Law No. 93-378. **United States statues at large**, 88, p. 476.
2. Public Law No. 94-588. **United States statues at large**, 90, p. 2949.

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4

REGIONAL FORAGE MODEL

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ABSTRACT

Timber management and land-use changes will affect the quality and quantity of land available for forage production. Previous national assessments of the forage resource in the United States have relied on qualitative methods, applied in isolation of the assessments of other renewable resources, such as wildlife, or timber. The objective of this study was to analyze quantitatively the impact of timber management and land-use changes on forage production in the southern United States. Recognizing that factors affecting primary production differ across major cover types, the forage production model consists of a forestland forage model and a pasture/rangeland model. Projections for forage production are linked with the projections for timber at the regional scale. In an analysis of a likely future for timber management in the southern United States, the results indicate that changes in land uses and timber management will shift a major portion of the supply of forage from natural pine type to planted pine types, and predicts an overall reduction in total forage in the region.

INTRODUCTION

A periodic assessment of all renewable resources on all forest and rangeland in the United States was mandated by the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974. This assessment must include a summary of the current and historical trends in forage production, and a projection of alternative future scenarios of forage production (Hoekstra and Joyce, 1988; Joyce et al., 1986). Projection of forage production in previous assessments has been qualitative and in isolation from assessments for other resources, such as timber.

Timber management activities and changing land use affect the quality and quantity of land available for forage production (Grelen, 1978). To assess the impact of timber management and land area changes on the future supply of forage, forage production relationships on pastureland, rangeland and forestland must be quantified and linked to regional projection models for timber and land area change.

Forage production in the South occurs on pastureland, rangeland (native pasture) and forestland (Hoveland, 1986). Forage production on these major land cover types has been quantified using different modelling approaches. The intensive management associated with improved pastures is reflected in the detailed physiological processes described in pasture models (Watson and Wells, 1985). Management of livestock under forests has traditionally been extensive, rather than intensive (United States Department of Agriculture [USDA], Forest Service, 1980),

and models used to estimate forage production under the changing overstory canopy have been less detailed than the pasture models (Wolters et. al., 1982). Models for both pasture and forest have focussed on specific sites for application and no work has been done at the regional level. While site-specific timber growth/yield models have existed for some time in the South, forage models and timber models rarely have been linked on a site-specific basis (Meyers, 1977).

Based on work by Lewis (1986) and Pearson (1982), a theoretical curve of forage production as a function of timber stand age on a specific site can be drawn (Figure 4.1). As the forest stand ages (the x-axis could be age, timber volume, basal area, or canopy closure), a dramatic drop in forage production is observed. Factors such as forest type, site class, stocking level, and timber management shift the slope and/or the intercept of this theoretical curve (Figure 4.1). Site-specific models have linked understory variables such as herbaceous cover or biomass with overstory variables such as basal area or canopy cover, using linear or logarithmic functions. These models were typically regression models based on long-term data collected at one site (reviewed in Joyce and Baker, 1987). Previous work by Joyce and Baker (1987) demonstrated the feasibility of developing similar models at the regional scale.

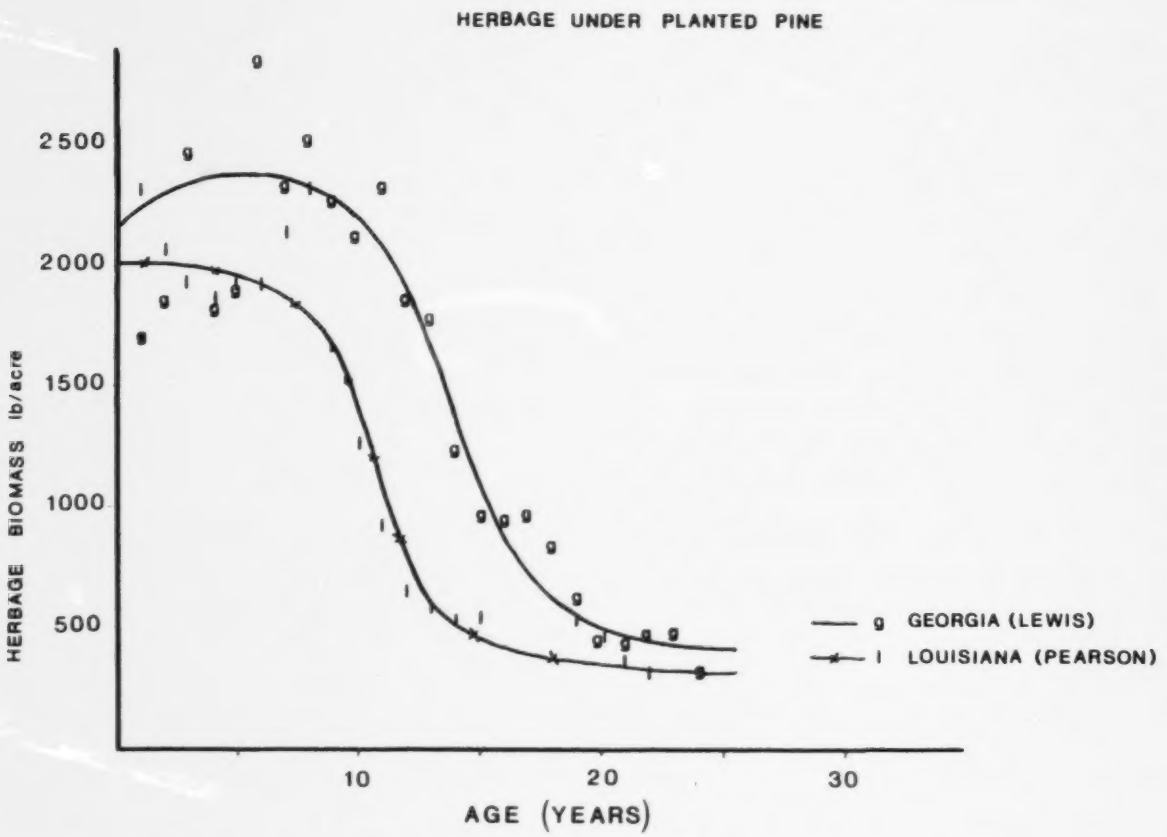
In this study, a regional forage production model was developed in a multiresource framework (Hoekstra and Joyce, 1988) and in which the modelling approach was specific to pasture/range and forest land types. The forage models were designed to be responsive to models that predicted regional shifts in land use (Alig, 1985 and 1986) and timber inventory characteristics (Tedder et al., 1987). Emphasis was placed on the resource interactions occurring on forested land. On pastureland and rangeland, changes in forage production are caused by shifts in acres from pasture and range use into other uses such as forest or urban. Thus the design of the modelling approach was to account for the effect of changes in acres on the total production of forage on pasture/rangeland in the South, rather than focussing on the detailed physiology of pasture/rangeland plant growth. For forestland, forage production models were patterned after previously developed site-specific models. Regression analysis was used to establish the relationship between herbaceous biomass and forest stand characteristics at the regional level. The forage models operated from the same land base although at different levels of resolution, reflecting the inputs from the land area model (state-level) and the timber inventory projection model (Timber Resource Inventory Model [TRIM] forest stand cells). In application, these analyses can be used to evaluate and project the impacts of changing land use and timber management on the forage resource.

METHODS

Pasture and Rangeland Forage Model

The impact of changing timber management and land area changes on forage produced on pasture/rangeland will primarily result from changes in the number of acres available for pastureland and rangeland. The structure of the pasture/rangeland model was designed to account for changes in land use on forage production at the state level. The pasture/rangeland model computes a state-level estimate of forage production based on the quantity and average quality of pasture and rangeland within the state. The total area in pasture and rangeland is projected by the land area model (Alig, 1986). The land-use category of pasture/range is a state-level category, thus shifts between pasture/range and other land uses can occur anywhere within the state. Pasture/rangeland acres were disaggregated into state-level area estimates of pasture and of range using the ratio of pastureland area to rangeland area as reported in the Soil Conservation Service (SCS) Natural Resource Inventory (NRI). Only five states in the South are reported to have rangeland acreage: Arkansas, Florida, Louisiana, Oklahoma, and Texas. In other states, the pasture/rangeland area was assumed to be entirely pasture.

FIGURE 4.1: THEORETICAL FORAGE PRODUCTION UNDER FORESTED STANDS



The rate of land area conversion from range to other land uses may be different than the rate of change from pasture to other land uses. However, because different definitions of range have been used in the previous inventories, computing the trend in pastureland versus rangeland conversions in the South was not possible. For this study, the relative per cent of pastureland versus rangeland area within the total area of pasture/range was assumed to hold over the projection period. For those states that currently do not report rangeland acres, no additional rangeland was added in the future. Changes in pasture and in range acres in this analysis were driven by the changes reported in pasture/rangeland by the land area projection model (Alig, 1986). Differences in forage production resulting from cover type (pasture versus range), climatic differences across the region, and past management were incorporated in the pasture/rangeland forage model.

Forestland Forage Model

Empirical models describing the overstory-understory relationship as a function of forest type, site class, stocking level, burn history, and changes in timber volume were developed for the major forest types using a regional multiresource inventory data set (McClure et al., 1979; O'Brien and Van

Hooser, 1983). Compatibility with forest stand dynamics projected at the regional level by the regional timber inventory projection model TRIM (Tedder et al., 1987) constrained the forestland forage model to work within the forest type classification used in the TRIM. Thus, the land base for the forestland forage model was the same land base used in the TRIM where acres of homogeneous cells of similar forest type, ownership, site class, stocking level, and age class were projected through the planning period. These homogeneous cells represent aggregations of forest stands scattered across the entire southeast or entire south-central regions of the South.

Forest Service Forest Inventory and Analysis (FIA) Multiresource Inventories reporting timber stand characteristics and herbaceous cover were available for three states in the southcentral region: Alabama, Louisiana, and Tennessee. Timber stand data from even-aged plots included: forest type, growing stock volume of timber, site class, stocking class, burn history, age class, ownership class, and per cent cover of browse. Definitions of class variables were the same ones used in the development of the TRIM (Table 4.1). Forest types included planted pine, natural pine, oak-pine and upland hardwoods. The timber projection model included the additional type of lowland hardwoods, however, this type was not modelled in the forest model because there are relatively few acres of this prime wildlife habitat in the South.

The understory variable measured in the multiresource inventory was per cent herbaceous cover which included cover of grasses and forbs. A special study conducted by the Southern Experiment Station FIA Unit was designed to develop the relationship between herbaceous cover and herbaceous biomass. This relationship was used to convert the multiresource plot data for herbaceous cover to herbaceous biomass. Biomass was the understory variable analyzed with the overstory variables.

In order to incorporate climatic information, precipitation data from the United States Weather Bureau was obtained for each county in which multiresource plots were sampled. Annual precipitation for the year before the inventory, the year of the inventory and the long-term mean were obtained for the weather station nearest the geographic centre of the county.

Factors affecting forage production at early stand ages may change over the lifetime of the forest stand. The non-linear relationship shown in Figure 4.1 was segmented into linear components within grouped age classes:

1. all plots of age less than 10 years,
2. all plots between 11 and 49 years, and
3. all plots older than 50 years.

Models for each of the linear components were developed to incorporate variability specific to grouped age classes. Thus, models were developed for each of the aggregated age classes within each of the four forest types: planted pine, natural pine, oak-pine, and upland hardwoods.

One assumption of regression analysis is that the dependent variables are distributed normally. The variable of herbaceous biomass per acre was tested for normality within the categories of site class, stocking level and burning history. In cases where normality was not met, the logarithm of herbaceous biomass was used as the dependent variable. Variables which violate the normality assumptions of regression analysis are often transformed using logarithms to stabilize the variables (Snedecor and Cochran, 1967).

Analysis of variance was used as a screening tool to determine the significant overstory factors associated with varying herbaceous biomass. Once these factors were determined, regression analysis was used to develop statistical models for herbaceous biomass. In using inventory data, neither the sample frequency nor the sample design are controlled for use in any subsequent analysis. This

TABLE 4.1: VARIABLES FROM THE MULTIRESOURCE SURVEY USED IN THE FORAGE MODEL

VARIABLE	DEFINITION
Forest Type	Planted Pine Natural Pine Oak-pine Upland Hardwoods
Site Index	High = >85 cubic ft/ac (>.97 cubic m/ha) Medium = 50-84 cubic ft/ac (.57-.96 cubic m/ha) Low = <50 cubic ft/ac (<.57 cubic m/ha)
Stocking Level	High = >100 per cent stocked Medium = 60-99 per cent stocked Low = <59 per cent stocked
Burn History	No evidence Recent (<3 years since burn) Old (>3 years since burn)
Age	10 year classes
Ownership	Public Industry Farmer and Miscellaneous Private

poses problems of uneven cell frequencies and of missing cells. These problems were minimized using Type III partial sums of squares of the general linear model (Conceptual Software, Inc., 1985; Freund and Liddle, 1981).

Using the regression models described above, the forestland forage model computed the per acre forage response and the regional total forage response based on these per acre estimates by forest type and age class. The timber inventory projection model TRIM projected total growing stock volume and total acres within each of the homogeneous cells. Growing stock volume per acre was computed for each of the homogeneous cells, and this information along with the total number of acres within each cell was the input to the forestland forage model.

RESULTS AND DISCUSSION

Analysis of Pasture/Rangeland Forage Production

The quantity of forage produced on pastureland differs considerably from the quantity of forage produced on rangeland. Within the pasture/rangeland forage model, pasture/rangeland acres were disaggregated into state-level area estimates of pasture and of range using the ratio of pastureland area to rangeland area as reported in the Soil Conservation Service (SCS) Natural Resource Inventory (NRI). Only five states in the South are reported to have rangeland acreage: Arkansas,

Florida, Louisiana, Oklahoma and Texas. In other states, the pasture/rangeland area was assumed to be entirely pasture.

Forage production is a function of the climatic conditions and past management. Pasture forage production estimates were obtained for each state from SCS Pasture Guides. State-level average annual hay production estimates are available in the USDA Agricultural Statistics (USDA, 1984). The potential pasture production as reported by the SCS pasture guides often exceeded the actual reported hay production. This difference is the result of decreased use of fertilizer in the region (Hendricks, 1986). The hay production estimates were used as the average pasture forage production estimates for each state.

Range forage production estimates were obtained for each state with range acres from the SCS Range Site Descriptions. While stocking level (animal units per month) is often adjusted for the condition of the range, forage production is not a linear function of range condition. Initial suggested stocking levels vary with the condition of the rangeland. Forage production estimates given in the Range Site Descriptions are associated with excellent condition range. Because it is difficult to associate variability in forage production with different condition classes, average forage production on excellent sites under median year precipitation was used as the average forage production on range sites. A state-level average was obtained from the average of all range sites.

The pasture/rangeland forage model analyzed shifts in forage production over the projection period. Land area shifts as projected for pasture/range were used to analyze forage production responses on rangeland and pastureland within a state and across the southeast and southcentral region.

Overstory-Understory Relationships

Herbaceous biomass under each of the four forest types was predicted using the variables shown in Table 4.2. Herbaceous biomass was not normally distributed across all classes, thus models for certain forest types and age classes, particularly Age Class 1 were constructed using the logarithm of herbaceous biomass. All models were statistically significant ($p \leq 0.05$, F-test). The correlation coefficients varied from .7 to .9. The regression models estimated herbaceous biomass per acre under each forest type and aggregated age class.

The growing stock volume represents the cubic foot volume per acre that can be harvested for commercial wood products. This was the timber variable projected in the timber inventory model TRIM, and thus served as the important link between the timber model and the overstory-understory model. This volume estimation did not include any part of a single tree which showed decay or roughness and consequently was commercially unusable. In addition, only commercial timber species were included in merchantable volume. Regional forage models were limited to using growing stock volume as a surrogate for the impact of trees on the understory until further improvements are made in the extant timber growth and yield models (Joyce and Baker, 1987).

Analysis of a Likely Future

Using likely trends in land-use shifts and timber management, the land area projection model and the TRIM were used to project state-level acres in the major land-use categories and regional-level acres in forest type and age categories (USDA, Forest Service, 1987). Forestland decreased from 56 per cent of the total land base to 53 per cent over the projection period. Forest type changes were dominated by the conversion of natural pine to planted pine. Planted pine increased from approximately 6 per cent of the total land base to over 14 per cent of the total land base. While the converted acres came primarily from natural pine in both regions, oak-pine and upland hardwood types were also converted over the projection period. Age class distributions varied initially by forest type. Over the projection horizon, significant increases in Age Class 1 (1-10

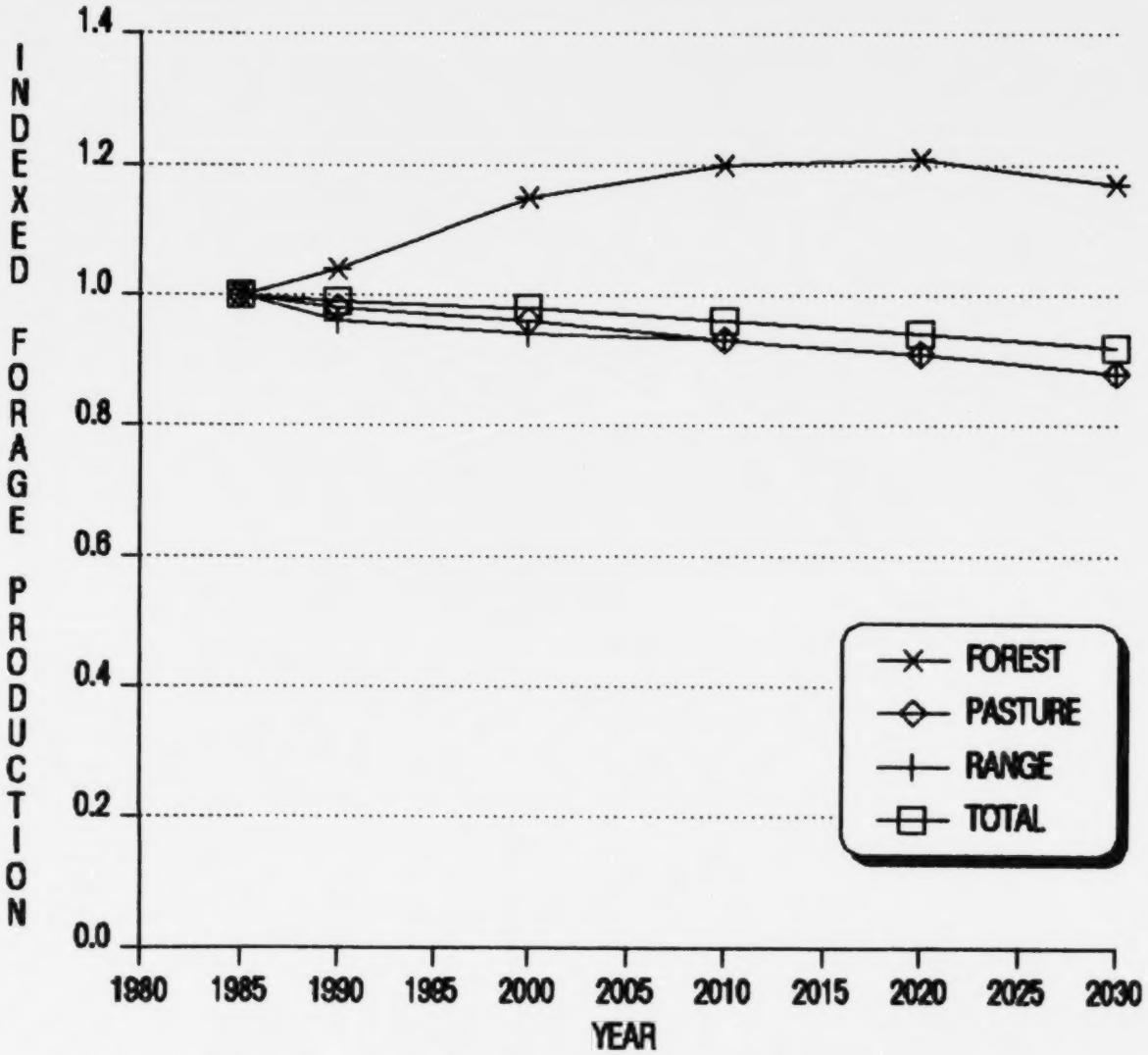
TABLE 4.2: ENVIRONMENTAL AND TIMBER VARIABLES SIGNIFICANT IN THE FOREST TYPE-AGE CLASS FORAGE MODELS

FOREST TYPE VARIABLES	AGE CLASS			
1	2	3	4	5 through 8
Planted Pine Precipitation Volume Stocking Level Burn History	Planted Pine Precipitation Volume Stocking Level Burn History Site Class Ownership	→	→	Planted Pine Same as Natural Pine Age 5+
Natural Pine Precipitation Volume Stocking Level Site Class Burn History Ownership	Natural Pine Precipitation Volume Site Class Age Ownership	→	→	Natural Pine Precipitation Volume Stocking Level Site Class Burn History
Oak Pine Precipitation Volume Stocking Level Site Class Burn History Ownership	Oak Pine Precipitation Volume Site Class Age Ownership	→	→	→
Upland Hardwoods Volume Precipitation Ownership Site Class Burn History	Upland Hardwoods Volume Browse Cover Stocking Level Age Class	→	→	Upland Hardwoods Volume Browse Cover Age Burn History

years) planted pine acres were seen.

The total amount of herbage produced from all lands: forest, pasture and range, decreases over the projection period (Figure 4.2). This decrease reflects the decrease in pastureland and rangeland acres. Pasture and range contribute the dominant portion of forage in the South. Forest herbage increased 12 per cent over the projection period, however the increase does not compensate for the decrease in pasture and range forage. The SCS Natural Resource Inventory (NRI) reported that between 80 to 95 per cent of the pastureland in the South is grazed. The decreases reported in the forage analysis indicate that at the current demand for grazing, the demand for grazing would have to be met by alternative sources. The SCS NRI also reported that less than 10 per cent of the forestland is grazed. Consequently, there appears to be a large reservoir of

FIGURE 4.2: TOTAL HERBAGE RESPONSE ON ALL LANDS, AND HERBAGE RESPONSE ON FORESTLAND FOR LIKELY FUTURE IN SOUTH



forage on forested lands.

Modelling the possible impacts of changing land use and timber management on forage production required a number of assumptions. This analysis assumes that forage production changes on forested lands predicted over the projection period are the result of changes in forest stand characteristics. Consequently, environmental factors that influence forage production (e.g., climatic change) are assumed to remain constant over time since no

measure of the change in these factors over time is available for the projection period. It is also assumed that timber management practices by forest types (e.g., spacing on pine plantations) or pasture management practices (fertilization application rates) will not change in a way that will affect forage production responses over the projection period. Incorporating these factors into a quantitative analysis of forage production at the regional level will require further research on the dynamics of forage production on forested stands.

CONCLUSIONS

This forage model was developed to evaluate the possible effects of changing land use and alternative timber management at the regional scale. Consequently, these analyses represent the changes in pastureland, rangeland and forestland acres as well as the changes in timber stand characteristics resulting from timber management. Because forage is primarily produced on pastureland and rangeland, changes in acres of pastureland and rangeland significantly impact total herbage produced and overshadow the changes resulting from timber management. Incorporation of alternative management strategies for pastureland and rangeland, such as fertilization, have not been incorporated into this analysis. Similarly, forage management on forested stands has not been included into this forage analysis. In order to make projections over time, several simplifying assumptions regarding these factors were made. It is important to keep these assumptions in mind when interpreting the results of this forage analysis. The forage analysis predicts what might occur when forage is not the primary resource being managed. This analysis represents a first generation effort of a multiresource analysis. With this experience, there is a basis for recommending future research activities that will permit explicit incorporation of the assumptions made in this analysis.

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5

WILDLIFE ABUNDANCE AND OCCURRENCE MODELS: APPLICATION IN REGIONAL RESOURCE PLANNING

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ABSTRACT

Incorporating wildlife resources into the planning and decision making process will require more than a description of current habitat and population status. Methodologies need to be developed that will permit assessment of wildlife resource impacts from future land management activities. In the past, qualitative approaches have been applied with little consideration for resource interactions such as timber on wildlife. The objective of this study was to evaluate quantitatively the impacts of changing land use and timber management on wildlife occurrence and abundance. Statistical models that correlated wildlife distribution and density with land use and land cover characteristics were developed across the South. Models were built for white-tailed deer, wild turkey, and red-cockaded woodpecker. Application of these models in an analysis of predicted changes in land use and timber management through 2030 indicate that density levels of deer and turkey will decline and the distribution of red-cockaded woodpeckers will become restricted to federally-owned land in the South.

INTRODUCTION

Ecological land surveys can be an important component in wildlife resource planning (Hoekstra and Flather, 1986; McClure et al., 1979). The utility of land base surveys in the planning process depends, in part, on demonstration that inventoried information can be used to evaluate wildlife habitat and populations. However, the planning process requires more than a description of wildlife habitat and populations. Methodologies need to be developed that will permit resource planning specialists to assess the multiple resource impacts from likely future management alternatives. Wiken (1982) described this need as ecological land evaluation, the final step of an ecological land survey and one that ultimately leads to the development of prescriptive resource management policy and programs.

In the United States multiresource evaluation is mandated by the Renewable Resources Planning Act of 1974 (PL 93-378). This Act requires the United States Department of Agriculture (USDA), Forest Service to conduct national assessments of all renewable natural resources. The assessment must include a description of the historical and current status of wildlife resources and projections of future inventories and uses of wildlife under alternative future scenarios (Hoekstra and Joyce, 1988).

One of the most insistent problems in meeting this legislative requirement is developing objective, quantitative methodologies that are appropriate for the scale of national assessments. There have been recent efforts to

develop objective models that relate wildlife species to habitat characteristics; however, the focus has been on evaluating resource development impacts at the site level (Hawkes et al., 1983). Geographic aggregation of site-specific models to produce larger scale summaries is currently impractical for national assessments. Also, there is a need to recognize that informed resource planning decisions cannot be made exclusively at the site level (Risser et al., 1984). More emphasis should be placed on analyses that explicitly address large geographic areas (Gall and Christian, 1984; Sanderson et al., 1979).

This paper describes the wildlife component of a regional multiresource modelling framework that is being applied to the southern United States (Hoekstra and Joyce, 1988). The objective of the wildlife modelling effort was to develop a regional modelling approach to predict changes in wildlife abundance and occurrence that was linked to models that predicted regional shifts in land use and timber management. A habitat-based approach was chosen because a direct link between wildlife populations and the entity altered by land management (i.e., habitat) is established. Also, the occurrence and abundance of wildlife species are generally recognized to be influenced by habitat characteristics. Although the influence of interspecific interactions and other non-habitat factors on animal populations is recognized (Flather and Hoekstra, 1985), information that permits consideration of such factors is limited and therefore rarely incorporated into analytical models of habitat. This analysis was patterned after that of Klopatek and Kitchings (1985). Multivariate statistical techniques were used to establish empirically the relationships between land use and forest vegetation, and relative abundance classes or occurrence of wildlife species. In application, these models can be used to evaluate and project the impacts of changing land use and forest vegetation characteristics on the wildlife resource as represented by the species modelled.

METHODS

Land Area Database

The study area extended over a 12 state region in the southern United States from eastern Texas and Oklahoma to Virginia. Estimates of land area by land use and forest vegetation characteristics were produced at the county level. United States Forest Service (FS) regional inventories (USDA, Forest Service, 1985) were used to obtain area estimates for forest cover types and age classes, by ownership (i.e., federal, forest industry, and other private). Soil Conservation Service (SCS) national inventories (USDA, Soil Conservation Service, 1982) were used to obtain estimates of all other land types (e.g., crop, pasture, range, and urban). Combining FS and SCS inventories to characterize total county land area resulted in discrepancies, when compared to Bureau of Census estimates of county area (United States Department of Census [USDC], Bureau of Census, 1970), since the two inventories are not mutually exclusive. Iterative proportional fitting (Deming and Stephan, 1940) was used to adjust FS and SCS inventory data to approximate more closely the total county land area reported by the Bureau of Census. Table 5.1 defines the independent variables used in the development of the wildlife models. All land area variables describe the areal proportion of each land use and land cover type within each county.

Wildlife Database

The two most important game species in the South are white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*) (USDA, Forest Service, 1981). Abundance data for these two species were obtained from the Southeastern Cooperative Wildlife Disease Study, University of Georgia. Maps depicting the distribution of abundance classes for deer in 1982 and turkey in 1980 were used to assign each county into one of three density classes (low, moderate, or

TABLE 5.1: DEFINITION OF LAND-USE AND LAND COVER VARIABLES USED TO *DEVELOP WILDLIFE MODELS*

VARIABLE ACRONYM	VARIABLE DEFINITION
TOTCRP	Total cropland acreage calculated by summing area estimates for row crops, close grown crops, horticultural crops, unplanted cropland, and other cropland
TOTPAST	Total pastureland and rangeland acreage calculated by summing area estimates for pasture, range and rotation hay and pasture
HUMAN	Total acreage associated with human development calculated by summing area estimates for urbanland, roads, railroads, strip mines and farm structures
NP	Total acreage estimates of natural pine
PP	Total acreage estimates of planted pine
OP	Total acreage estimates of oak-pine
UH	Total acreage estimates of upland hardwood
LH	Total acreage estimates of lowland hardwood
AGE1[1]	Age Class 1 area across all forest types (except PP)
AGE2[2]	Age Class 2 area across all forest types (except PP)
AGE3[3]	Age Class 3 area across all forest types (except PP)
HWAGE1	Age Class 1 area across hardwood types
HWAGE2	Age Class 2 area across hardwood types
HWAGE3	Age Class 3 area across hardwood types
PNAGE1	Age Class 1 area across pine types (except PP)
PNAGE2	Age Class 2 area across pine types (except PP)
PNAGE3	Age Class 3 area across pine types (except PP)

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[1] Age Class 1: 0-20 years
[2] Age Class 2: 21-50 years
[3] Age Class 3: 50+ years

high). Density estimates were assumed to be at the capacity of the habitat.

The red-cockaded woodpecker (*Picoides borealis*) was chosen because of its sensitivity to timber management practices (Lennartz and McClure, 1979), and its status as a threatened and endangered species. This bird lives in a social group called a clan which is made up of two to nine birds with one breeding pair (Hooper et al., 1980). Several cavity trees are used by the clan for roosting and nesting and these sites define a colony. A search of the literature provided information on the distribution of active colonies across the South (Baker, 1982; Carter et al., 1983; Jackson, 1978; James et al., 1981; Wood and Wenner, 1983). State fish and wildlife agencies, FS biologists, and state Natural Heritage Programs were also contacted for county level estimates of active colonies.

Model Building and Application

Discriminant function analysis was used to establish the statistical relationships between land base descriptors and relative density classes or occurrence of wildlife species. Discriminant analysis generates classification functions that can be used to predict group membership based on a set of independent variables (Johnson and Wichern, 1984). Counties served as the sampling unit and therefore the set of objects to be classified. Model adequacy was evaluated based on classification accuracy, expressed as a percentage of the counties correctly classified. All statistical analyses used the Statistical Analysis System (SAS Institute Inc., 1985a and 1985b).

For deer and turkey a total of 772 counties, stratified across six physiographic regions, were used to build the discriminant models. The stratification was based on SCS Major Land Resource Areas (USDA, Soil Conservation Service, 1981), and corresponded to the major physiographic regions across the South (Figure 5.1). Peninsular Florida and gulf coast counties in Texas and Louisiana were not included because the small number of counties did not permit development of multivariate models. Counties are classified as supporting low, moderate, or high densities of deer or turkeys by the models.

The red-cockaded woodpecker analysis was restricted to the coastal plain regions of the South -- the primary range of the species. Separate models were built for the southeast region (Virginia, North Carolina, South Carolina, Georgia and northern Florida) and southcentral region (Alabama, Tennessee, Mississippi, Louisiana, Arkansas and eastern Texas and Oklahoma). The models predict presence or absence of active nesting colonies within a county.

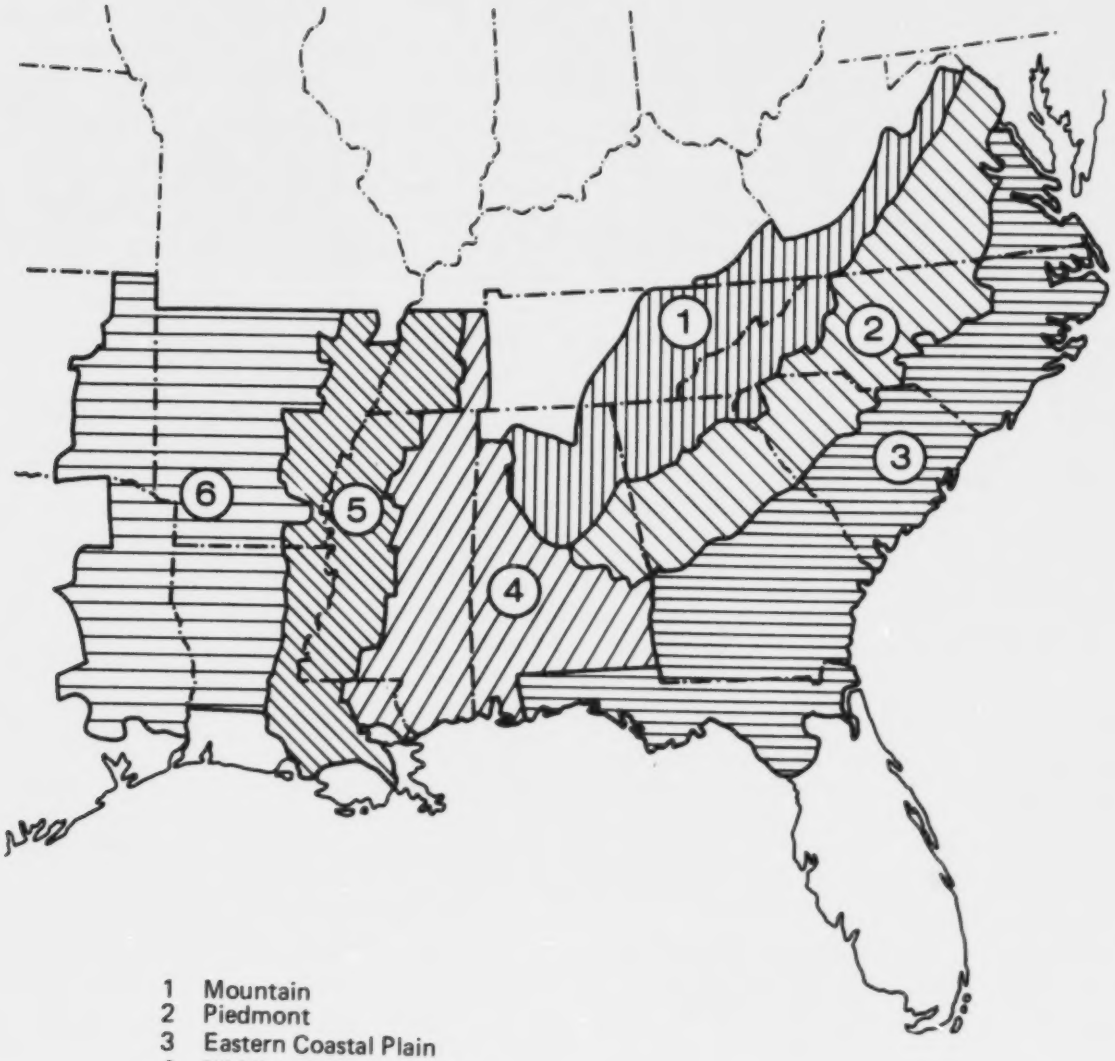
Two assumptions critical to discriminant analysis are:

1. multivariate normally distributed independent variables, and
2. similar covariance structure between classification groups (Johnson and Wichern, 1984).

Multivariate normality was examined indirectly through univariate tests of normality (Habbema and Hermans, 1977). Proportion variables violate normality, therefore all variables were transformed using the arcsine transformation. The covariance structures were dissimilar which resulted in the development of quadratic discriminant functions rather than linear discriminant functions, as recommended by Williams (1983).

Selection of model variables was based on three steps. First, significant deviations from normality resulted in elimination of variables from further consideration. Second, results from univariate analysis of variance were used to select those variables that were significantly different among the density or occurrence classes. Pairs of highly correlated variables were separated to eliminate

FIGURE 5.1: LAND BASE STRATIFICATION FOR WHITE-TAILED DEER AND WILD TURKEY MODELS



1 Mountain
2 Piedmont
3 Eastern Coastal Plain
4 Mid-South Coastal Plain
5 Mississippi Valley
6 Western Coastal Plain

redundancy. The remaining variables were used to develop preliminary discriminant models. Third, preliminarily selected variables were sequentially removed from the model and the results examined for changes in discriminatory power. Increased classification accuracy resulted in removal of that particular variable from the model. This process selects a model with the minimum number of independent variables and maximum classification accuracy (Habbema and Hermans, 1977).

Regional projections of wildlife density and occurrence used the classification functions generated by discriminant analysis to classify "new" counties for which group membership (e.g., high, moderate, or low density) was not known. "New" counties were defined by changes in land use and timber management as predicted by the land base projection models for the years 1985, 1990, 2000, 2010, 2020, and 2030. Acreage projections of major land-use categories (forest, crop, pasture, and urban) were made by econometrically based models (Alig, 1984). Changes associated with forest age class acreage by ownership were provided by the timber inventory projection model (Timber Resource Inventory Model [TRIM]) (Tedder, 1983; Tedder et al., 1987). Coupling these models required consistency between wildlife model variables and land base projection outputs. For this study, the linkage was achieved by ensuring that all models operated from a commonly defined land base.

Deer and turkey response to changing land use and land cover patterns was assessed by calculating a weighted average density. Average density was calculated by taking the average probability of membership in each density class across all counties (probabilities were provided by the discriminant analysis), multiplying these probabilities by the midpoint density levels of each class, and summing to get a single density estimate. Midpoint density levels of 9, 19 and 29 deer per mile^2 (per 1.6 km^2) and 3, 7.5 and 14 turkeys per mile^2 (per 1.6 km^2) were assigned to the low, moderate and high density classes. Red-cockaded woodpecker response was measured by changes in the number of counties supporting active nesting colonies.

RESULTS AND DISCUSSION

Wildlife Habitat Relationships

Regionwide model classification accuracies for white-tailed deer and wild turkey were 79 per cent and 82 per cent, respectively. Classification success across strata ranged from 73 per cent to 85 per cent for white-tailed deer and 75 per cent to 87 per cent for wild turkey. In all cases, the number of counties correctly classified were significantly greater than a random model ($p < 0.001$, *kappa statistic*) (Titus et al., 1984).

White-tailed deer and wild turkey habitat relationships established in the analysis were consistent with expert review and reported life history information. White-tailed deer densities were negatively related to increased area of human-related land use. Cropland had a negative influence on deer density in strata with high levels of agricultural land use. Cropland had a positive influence on deer density in strata that were dominated by forest cover, presumably because of increased land type diversity. Higher deer densities were also associated with early forest successional stages as represented by young forest age classes.

Wild turkey densities were negatively associated with increased area in cropland and human-related land uses. Increased area in natural forest types, in particular upland hardwood and lowland hardwood, and old age classes of hardwood types were associated with higher turkey densities.

The red-cockaded woodpecker model had an 80 per cent classification accuracy regionwide and ranged from 79 per cent in the southeast region to 82 per cent in the southcentral region. Because red-cockaded woodpeckers are a habitat specialist, the habitat

relationships established were a function of a small subset of available variables. Presence of active red-cockaded woodpecker colonies was primarily dependent upon large acreage in natural pine stands and old age classes of natural pine and oak-pine. Secondarily, increased acreage in upland hardwood and cropland were associated with absence of active colonies.

Analysis of a Likely Future

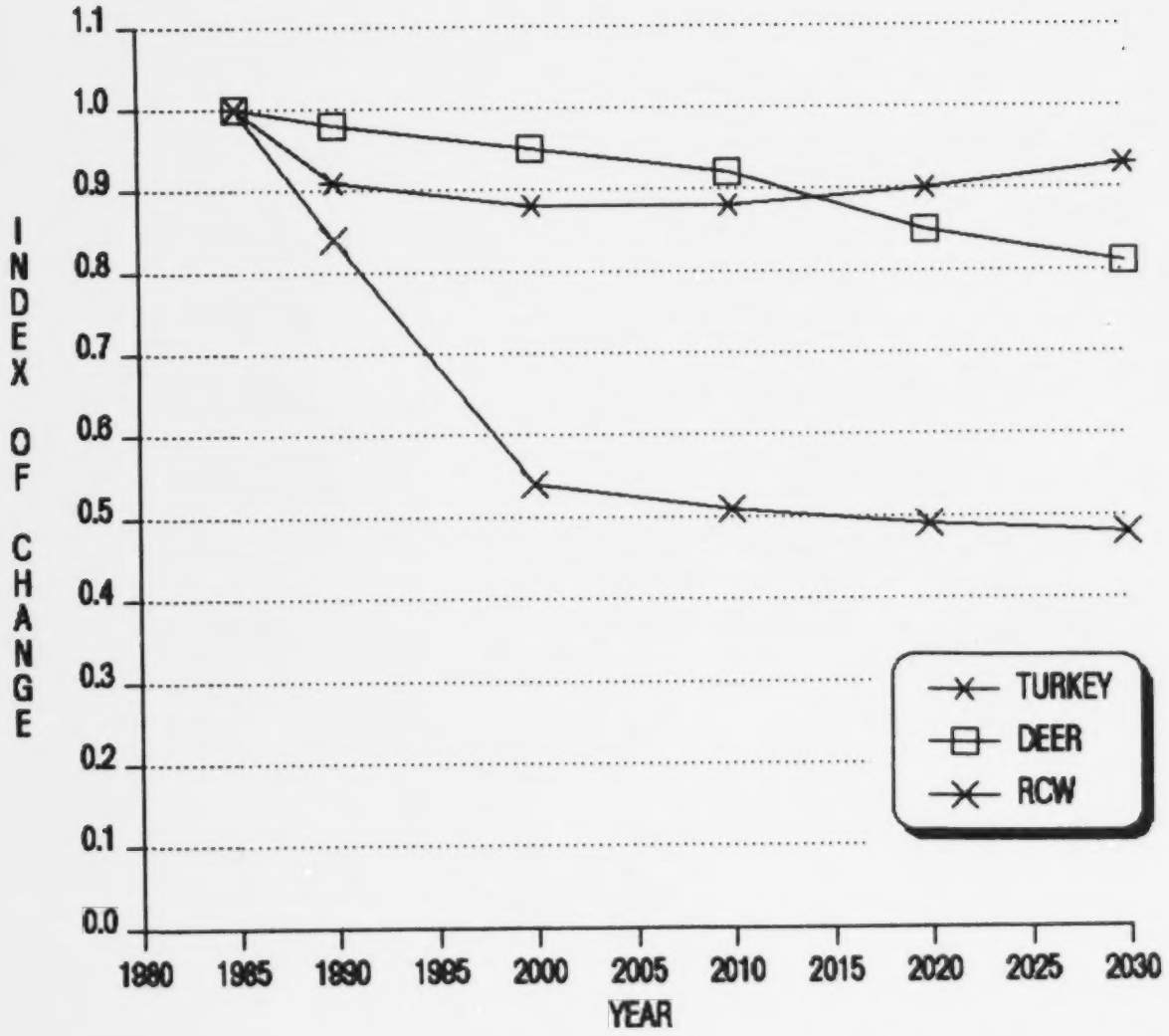
Evaluating possible impacts on wildlife resources resulting from land management activities was accomplished by explicitly linking land area and timber inventory models to habitat-based wildlife models. The TRIM and the land area projection model were run assuming likely trends in land use and timber management. Land area changes for the entire South between 1985 and 2030 are summarized in Table 5.2. The predicted trends in land use and forest management indicated increased urbanization and more intensive forest management. Forestland area in general, and to a lesser degree pastureland, declined over the projection period. Cropland showed slight gains (16.7 per cent to 17.4 per cent), while human-related land uses showed relatively large increases in area (7.3 per cent to 11.1 per cent). The most notable forest type changes that occurred were conversion of natural forest types to pine plantations. Area in pine plantations increased from 6.6 per cent of the land base to 13.5 per cent. Natural pine accounts for the majority of the converted acres (12.6 per cent to 6.6 per cent), however, oak-pine and upland hardwood types were also harvested and planted to pine. Significant gains in older and younger hardwood age classes and losses of older pine were the major changes in forest stand structure.

White-tailed deer, a generalist in its habitat requirements, was the least explicit in its response to changes in any single land cover characteristic. The deer models predicted that the average density will decline by 18 per cent (17.3 to 14.1 deer per mile^2 [per 1.6 km^2]) from 1985 to 2030. Figure 5.2 shows the wildlife responses indexed to 1985 density levels. The decline was attributed to an overall loss of forested habitat acres, specifically upland hardwoods and the conversion of natural pine and oak-pine stands to planted pine. Increased acreage in human-related uses including urbanland and roads also contributed to the overall decline in deer numbers. Human-related land use

TABLE 5.2: PROJECTED PER CENT COMPOSITION OF THE TOTAL LAND BASE UNDER A LIKELY FUTURE

LAND VARIABLE	1985	2000 %	2030
Total Forest	56.2	54.8	53.3
TOTCRP	16.7	17.0	17.4
TOTPAST	15.6	15.0	13.9
HUMAN	7.3	9.1	11.1
NP	12.6	8.3	6.6
PP	6.6	10.7	13.5
OP	8.3	7.2	6.7
UH	19.4	19.2	17.9
LH	9.4	9.4	8.6
AGE1	13.6	11.7	17.6
AGE2	27.8	23.6	12.1
AGE3	8.2	8.8	10.2
HWAGE1	9.6	8.1	14.0
HWAGE2	20.1	19.5	9.2
HWAGE3	7.3	8.2	10.0
PNAGE1	7.0	6.3	7.1
PNAGE2	12.2	39.0	5.6
PNAGE3	1.7	1.0	.6

FIGURE 5.2: INDEXED WHITE-TAILED DEER, WILD TURKEY, AND RED-COCKADED WOODPECKER RESPONSES TO A LIKELY FUTURE LAND BASE PROJECTION



not only directly reduces available habitat but is generally associated with increased mortality from illegal hunting pressure and human-related disturbance.

Wild turkey have more specific habitat requirements than deer and were closely tied to the hardwood component of the forest land base. Increased human-related land-use acres and the general loss of upland hardwood and oak-pine types contributed to the early decline (Figure 5.2). However, after the year 2000 average turkey density leveled off and recovered due to increased acres in older

hardwood stands. The predicted decline in turkey densities over the planning period is 7 per cent (5.9 to 5.5 turkeys per mile^2 [per 1.6 km^2]).

The red-cockaded woodpecker is the most specialized species evaluated. This species' dependence on mature pine stands resulted in a close tracking of counties supporting active colonies and acres in the oldest pine age class. Conversion of natural pine stands to planted pine, and the associated loss of older age classes of natural pine was most dramatic on private ownerships. The rapid decline in the number of counties supporting active colonies through the year 2000 is due almost entirely to losses of active colonies in counties that are primarily in forest industry or other private ownerships (Figure 5.2). The leveling off in the number of counties that support active colonies is associated with those counties that have a high proportion of federally owned land within their boundary. Federal owners manage timber less intensively and retain more area in older pine stands. Federal ownership is predicted to be extremely important to the maintenance of viable populations of red-cockaded woodpeckers.

CONCLUSIONS

The wildlife models were designed to evaluate the possible effects of changing land use and timber management at the regional scale. The models represent empirical relationships between habitat (as represented by land base descriptions at the county level) and observed wildlife density and occurrence. Under a future of increased urbanization and more intensive timber management, white-tailed deer, wild turkey, and red-cockaded woodpecker were predicted to decline over the planning period. However, the models project what may occur if no future consideration is given to wildlife or timber management activities that may alter the projected trends. For example, the effects of wildlife incentive programs or changes in the perceived economic value associated with wildlife have not been incorporated in the current analysis. In order to make projections over time, simplifying assumptions regarding these factors had to be made -- namely that they remained constant over time. It is important to keep these assumptions in mind when interpreting the results of the wildlife analysis.

The objective of the wildlife modelling effort was to provide results from which planners and policy makers could evaluate possible impacts from changing land use and timber management activities. In the context of the multiresource framework it represents an initial effort to incorporate wildlife resource considerations quantitatively into an analysis of the South's timber resource. Now that the framework has been specified and applied, there is a basis for recommending research activities that will improve our ability to analyze possible wildlife responses to the management of all resources.

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6

REGIONAL COLD-WATER FISH ABUNDANCE PROJECTIONS

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ABSTRACT

The United States Department of Agriculture (USDA), Forest Service has a legislated responsibility to assess national resources now and into the future. The analysis objective for fish resources is to project relative abundance of fish species from changes of land use and land cover. The southeastern region of the United States (Virginia, North Carolina, South Carolina, and Georgia) was selected as the study area to develop a modelling approach. Trout abundance data for streams in the cold-water areas of North Carolina and Virginia were aggregated into watersheds of the United States Geological Survey flow gauges. County land descriptions were proportionally allocated to each watershed. A quadratic discriminant model, developed from this watershed database, predicts trout abundance class membership as a function of runoff and per cent of each watershed in various land-use and land cover categories. In response to a future projection of likely land use and timber management trends through 2030, the model predicts a decline of trout density in trout streams for the cold-water areas of the southeastern region.

INTRODUCTION

Traditionally, fish have been related to their immediate environment, the stream. However, streams are imbedded within the landscape of the watershed, and the stream environment is affected by land-use activities within its watershed. For large-scale land planning, fish habitat relationships in streams are not adequate, and the fish habitat must be extended to the watershed. For national assessments required in the United States by the Renewable Resources Planning Act of 1974 (PL 93-378), the national scale requires a regional approach to fish analysis.

This research, to develop a modelling approach to regional analysis of fish resources, is part of a study designed to assess the timber situation, including projected futures, in the southern United States. Projections of acreage in various land uses, cropland, range and pasture, human land uses, and major forest cover types and structures (age classes) are made by three economic and timber projection models (Hoekstra and Joyce, 1988, Figure 3.1). Fish were identified as a resource that depends on the same land base as does timber, and which might be affected by changes in land use and land cover patterns (Joyce et al., 1986; Hoekstra and Joyce, 1988). Changes in land use and land cover can influence the fish resource directly or indirectly through changes in water quantity. Within the multiresource framework (Hoekstra and Joyce, 1988, Figure 3.1), there is no analysis of how management for fish influences timber; thus, this is an impacts analysis for fish. The analysis will identify changes in

the land base that may create changes in the fish resource.

Regional scale models of fish abundance have never been developed. Even site-specific stream models that predict fish abundance from habitat characteristics are rare compared to terrestrial wildlife models of this type (Hawkes et al., 1983). Site-specific analyses of fish abundance were deemed inappropriate for the regional scope of this study because analyses developed at one spatial scale (e.g., a stream) cannot generally be applied to another disparate scale (e.g., the South) (Risser et al., 1984). The specific objective of the study, namely, to assess the effect of a changing timber resource on the fish resource within the multiresource framework requires a new modelling effort to link the fish resource to the common land base (Joyce et al., 1986; Hoekstra and Joyce, 1988) and respond to changes in that land base. Since we have no known mechanistic relationships between land use and fish abundance at the regional scale, a statistical approach was selected to establish an empirical relationship for estimating fish abundance from changes in land use and forest cover types. Multivariate statistical techniques are particularly well-suited for habitat analyses (Shugart, 1981) and, properly designed, can produce resource predictions.

METHODS

Water and Land-Use Data

An appropriate sampling unit must first be selected with a statistical approach. Ideally, sampling units are small enough to minimize problems of spatial heterogeneity in landscapes (Risser et al., 1984) and to provide sufficient sample size for multivariate analysis. The fish model is further constrained by the need to fit within the multiresource framework (Hoekstra and Joyce, 1988, Figure 3.1) and accept input from a water model that projects runoff for United States Geological Survey (USGS) gauging stations in WATSTORE; those gauging stations, therefore, define the sampling unit for fish models. Sampling units are the watersheds behind the gauging stations. The total range of watershed size for the cold-water fish model is 39 to 3,050 square miles (62.8 to 4,908.4 km^2); but 85 per cent of the watersheds fall in the 100 to 700 square mile (160.9 to 1,126.5 km^2) range. Annual average instantaneous flows (cubic feet per second) recorded by the USGS gauges over the period 1973-1983 were converted to acre-feet per acre per year to standardize for drainage area. Thus, water quantity is a measure of runoff (feet per year). The runoff measure was necessary to standardize flow for watershed drainage area and to produce a measure that could be assumed applicable to the watershed as a unit.

The watershed land-use and land cover data were derived from county land-use data. Counties are the smallest land unit for which land-use and land cover data are available. The county land-use and land cover data were obtained from the Soil Conservation Service (SCS) National Resource Inventory (NRI) (USDA, Soil Conservation Service, 1982) and the United States Forest Service Forest Inventory and Analysis (FIA) (USDA, Forest Service, 1985) surveys. These databases were adjusted by iterative proportional fitting (Deming and Stephan, 1940) to approximate total county land area reported by the Bureau of Census (United States Department of Census [USDC], Bureau of Census, 1970). Proportions of each county contributing to each watershed were determined by planimetry or extracted from a digitized database of county-USGS Hydrologic Cataloging Unit intersections. Acres from each county-watershed intersection were summed for each watershed by land use and converted to proportions of each watershed in the NRI land-use and FIA land cover categories. The suite of independent variables, runoff and the land-use and land cover categories, are listed in Table 6.1.

Fish Population Data

Regional fish analyses are limited by the availability of suitable databases. Fish population data have been collected by state agencies and are inconsistently available.

TABLE 6.1: DEFINITION OF RUNOFF AND LAND-USE AND LAND COVER VARIABLES[1] USED TO DEVELOP REGIONAL FISH MODELS

VARIABLE ACRONYM	VARIABLE DEFINITION
RUNOFF	Average over 1973-1983 of mean annual runoff (feet per year)
TOTCRP	Total cropland, including row crops, close grown crops, horticultural crops, unplanted cropland, and other cropland
TOTPAST	Total pastureland and rangeland, including pasture, range, and rotation hay and pasture
HUMAN	Total land associated with human development, including urban land, roads, railroads, stripmines, and farm structures
NP	Total estimates of natural pine
	Estimates of natural pine by age class:
NPA1	Age Class 1: 0 - 20 years
NPA2	Age Class 2: 21 - 50 years
NPA3	Age Class 3: 50 + years
PP	Total estimates of planted pine
OP	Total estimates of oak-pine
UH	Total estimates of upland hardwood
	Estimates of upland hardwood by age class:
UHA1	Age Class 1: 0 - 20 years
UHA2	Age Class 2: 21 - 50 years
UHA3	Age Class 3: 50 + years
LH	Total estimates of lowland hardwood
HWAGE1	Estimates for Age Class 1 across hardwood types (oak-pine, upland hardwood, lowland hardwood)
HWAGE2	Estimates for Age Class 2 across hardwood types (oak-pine, upland hardwood, lowland hardwood)
HWAGE3	Estimates for Age Class 3 across hardwood types (oak-pine, upland hardwood, lowland hardwood)

[1] RUNOFF must be transformed by natural log and land-use and land cover variables (proportion of total land) must be transformed by arcsine-square root to meet the normality assumption.

Fisheries have been stratified into cold-water and warm-water fisheries to eliminate a major source of regional variability and orient the analysis to specific fish resources. For this study, state surveys of cold-water streams in North Carolina (Bonner, 1983) and Virginia (Mohn, 1980) were selected because the state agencies recently collected data with similar methods, and because these two states have the largest cold-water fisheries in the southeast region (Figure 6.1). Three species of trout are present in these waters: brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdneri*); however, in the analysis the species were considered as a group. A total of 1,311 stream samples from the mountain areas of North Carolina (537 streams sampled 1978-1981) and Virginia (744 streams sampled 1975-1979) comprise the cold-water fisheries database.

Both state surveys recorded trout numbers in stream samples. Trout numbers were converted to density (trout per acre of stream) for each stream, and the 1,311 stream samples were assigned to watersheds based on recorded location information. Within watersheds, many stream samples contain no trout. Absence of trout in a sample is an ambiguous condition (we cannot determine whether there were no trout or whether trout were present but not captured), and incorporation of zero density in the data sets for individual watersheds creates a statistically intractable distribution. Therefore, all stream samples with a trout density of zero were eliminated. After the streams with no trout were eliminated from the database, the abundance estimates were found to be log-normally distributed within watersheds, and the density estimate for watersheds is the geometric mean of stream trout densities. To minimize errors that might result from assumptions made to calculate density, numerical estimates were converted into three abundance classes: low, at least one individual to 100 trout per acre (per .4 ha) (20 watersheds); medium, 100-160 trout per acre (per .4 ha) (19 watersheds); and high, more than 160 trout per acre (per .4 ha) (21 watersheds). Thus, classes of trout density (number per unit area) in those streams that do have trout are predicted by the model.

Model Building and Application

Discriminant function analysis was used to develop a classification from the land and water data, capable of predicting trout density group membership from land-use and water quantity projections. Linear discriminant function analysis has been used to produce statistical models for both descriptive and predictive purposes. However, linear discriminant function analysis is sensitive to two assumptions about the data; multivariate normality of independent variables within classification groups and homogeneity (or similarity) of covariance matrices among classification groups (Morrison, 1967). Ecological data frequently do not satisfy these two assumptions of linear discriminant function analysis; therefore, a non-linear, quadratic discriminant function analysis is preferred (Williams, 1983). The Statistical Analysis System (SAS Institute Inc., 1985a and 1985b) package used here includes tests for univariate normality and homogeneity of covariances and a procedure for the required quadratic analysis.

In this analysis, since sample sizes are small, a subset of independent variables must be selected that are relatively uncorrelated and produce the best discrimination among classes. Instead of using a statistical (e.g., stepwise) procedure to select variables, which introduces attendant problems (Habbema and Hermans, 1977; Johnson, 1981), the following procedure was followed. The suite of possible independent variables (from Table 6.1) was grouped to minimize correlations among variables. Candidate models were constructed by a sequential elimination of variables from each group of variables. The model with the minimum number of independent variables and with the maximum reclassification success (per cent of watersheds that are correctly classified in a reclassification by the model) was selected (Habbema and Hermans, 1977).

For making regional projections of the trout resource, the model must be extended into

FIGURE 6.1: COLD-WATER FISH AREA OF THE SOUTHEAST[1]

[1] Watersheds in the darkly shaded areas in Virginia and North Carolina were used to create the trout density model. Projections were made for that area plus the lightly shaded area in Georgia and South Carolina.

areas of northern Georgia and extreme northwest South Carolina where trout are known to occur, but where abundance data are lacking (Figure 6.1). Fourteen watersheds were added to the original 60 from Virginia and North Carolina to make the southeast projection. Trout density for the southeast region was estimated as follows. Classification produces a posterior probability of membership in each of the three classes for each watershed; averaged over all watersheds, those probabilities become regional probabilities for each class. Expected densities of 50, 130, and 363 trout per acre (per .4 ha) (the midpoints of each class) were assigned to the low, medium, and high density classes, respectively. Average regional probabilities were multiplied by these expected densities and summed, to obtain a single estimate of trout density (trout per acre of trout stream).

Regional projections of land use and forest types for 1985 through 2030 from the land area model (Alig, 1984) and timber model (Tedder, 1983; Tedder et al., 1983) were applied to the discriminant function analysis model to produce an analysis of a likely future for the trout resource. The projection describes the timber situation, provided that current expectations about supply and demand are realized. A number of timber related assumptions were incorporated in the land projection, including a level of timberland management that is more intense than current management. Projected land use and land cover acres for the years 1985, 1990, 2000, 2010, 2020, and 2030 were converted to proportions of watershed by the method described above. For a watershed, runoff (feet per year) is predicted by a matrix of water yield changes for shifts of watershed land area in each land-use and cover category.

RESULTS AND DISCUSSION

Analysis of Fish Habitat Relationships

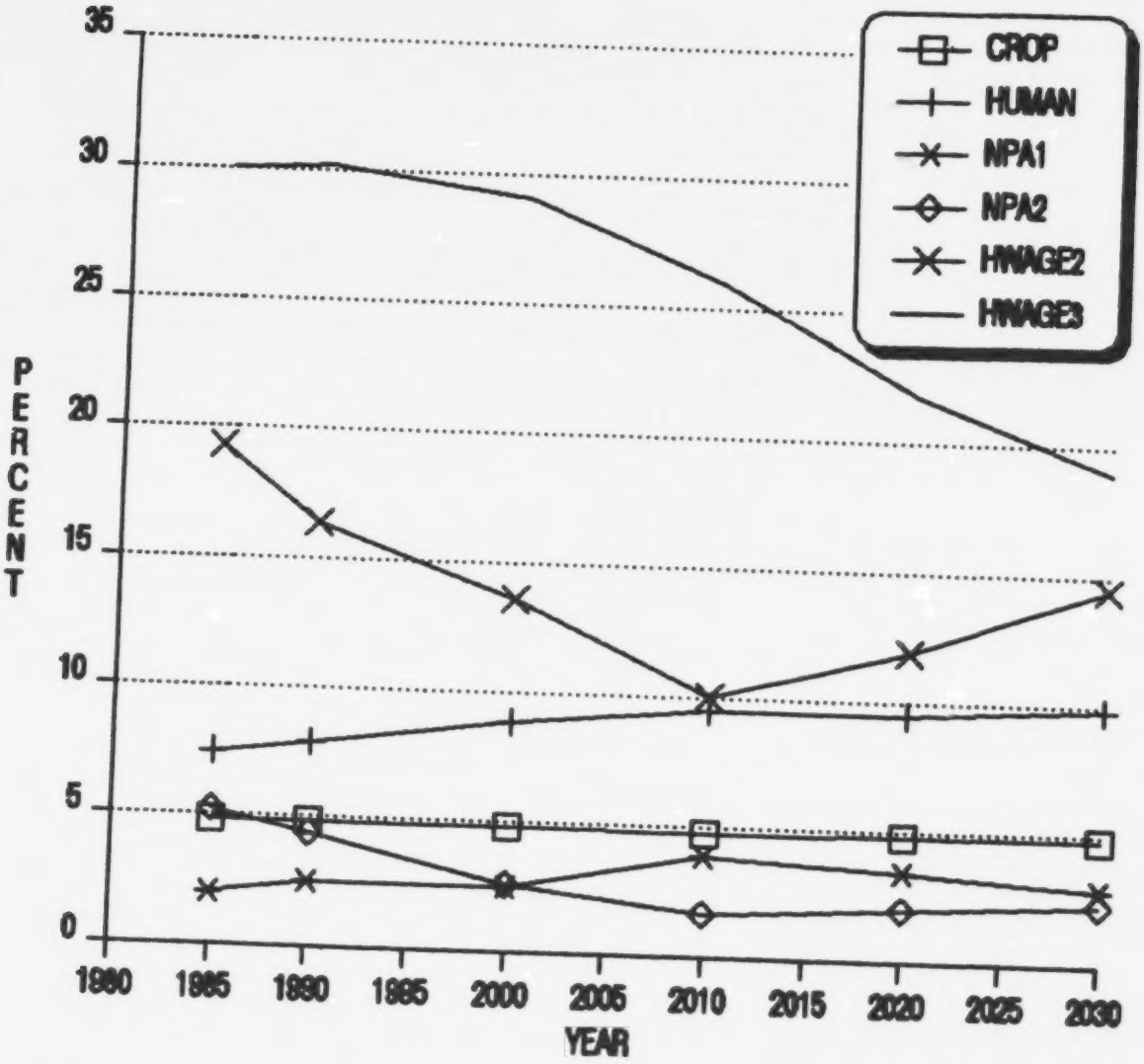
To meet the normality assumption, a natural logarithmic transformation of runoff and an arcsine-square root transformation of land-use proportions were necessary. Several land-use variables were eliminated because the normality assumption could not be met after transformation.

The selected model classifies trout density class as a quadratic discriminant function of seven independent variables (RUNOFF, TOTCRP, HUMAN, NPA1, NPA2, HWAGE2, and HWAGE3; see Table 6.1 for descriptions) with a reclassification success of 78.3 per cent. In this model, high trout density is associated with the highest coverage of old-age hardwoods (HWAGE3) and the lowest proportion of land devoted to human uses (HUMAN) and cropland (TOTCRP).

Analysis of a Likely Future

Land-use and forest cover type projections were made for the entire southern United States; in the following discussions and figures, data are given only for the cold-water area of the southeast. The proportion of old-age hardwoods (HWAGE3, Figure 6.2) in the land base declines dramatically after 2000. Middle-age hardwoods (HWAGE2, Figure 6.2) decline through 2010, but this decline largely represents growth and aging of stands to the old age class. Hardwoods comprise the most important part (54.2 per cent) of the total land base in the cold-water fisheries area. Total hardwoods decline only slightly (to 53.2 per cent in 2030) over the projection period; however, the age structure changes dramatically as older hardwood stands are cut and later regenerate. In the natural pine age classes, the dynamics between young (NPA1) and middle (NPA2) age classes also represent a cycle of cutting and regrowth (Figure 6.2). The importance of natural pine in the cold-water area land base is minor, and these small changes, relative to those in hardwood age classes are not likely to exert a large influence on trout density. Cropland remains nearly constant throughout the projection period, and human land uses increase predictably (Figure 6.2). Over the projection period, annual runoff increases by about one inch (2.54 cm). These projections of land use and forest type age classes and of runoff result in a decline of 47 trout per acre (per .4 ha) from the 1985 density of

FIGURE 6.2: LIKELY FUTURE PROJECTIONS FOR TROUT DENSITY PREDICTOR VARIABLES, LAND USES AND COVER TYPES IN COLD-WATER AREA[1] OVER THE PROJECTION PERIOD



[1] Percentage of total land

173 trout per acre (per .4 ha) (Figure 6.3), corresponding to a 27 per cent decline between 1985 and 2030.

The decline of trout abundance is largely in response to the decline of old-age hardwoods (over 50 years of age) and increased human land use over the projection period. In the analysis of current trout density, highest trout density was associated with highest proportion of old-age hardwoods, and lowest trout density was associated with highest proportion of human land uses. Implicit in these relationships are factors such as water temperature, instream cover, and shading that are positive for trout in areas with old hardwoods and negative for trout in areas with large amounts of human land uses. As older hardwood acreage declines over time, shading declines and water temperature increases. At the same time human land use is increasing at the expense of high quality trout habitat. Trout density declines under these land-use and forest cover changes and the attendant modification of trout habitat.

CONCLUSIONS

The purpose of the fish analysis was to project changes of trout density in trout streams in response to projected changes in acres of both land uses and forest types. The trout abundance quadratic discriminant function model assigns a watershed with a particular land description to one of three relative trout density classes. Trout density is a function of both land in forest type age classes and land devoted to cropland and human land use. Thus, changes in acres of forestland are considered in combination with changes in acres of non-forest land uses to produce the trout density results.

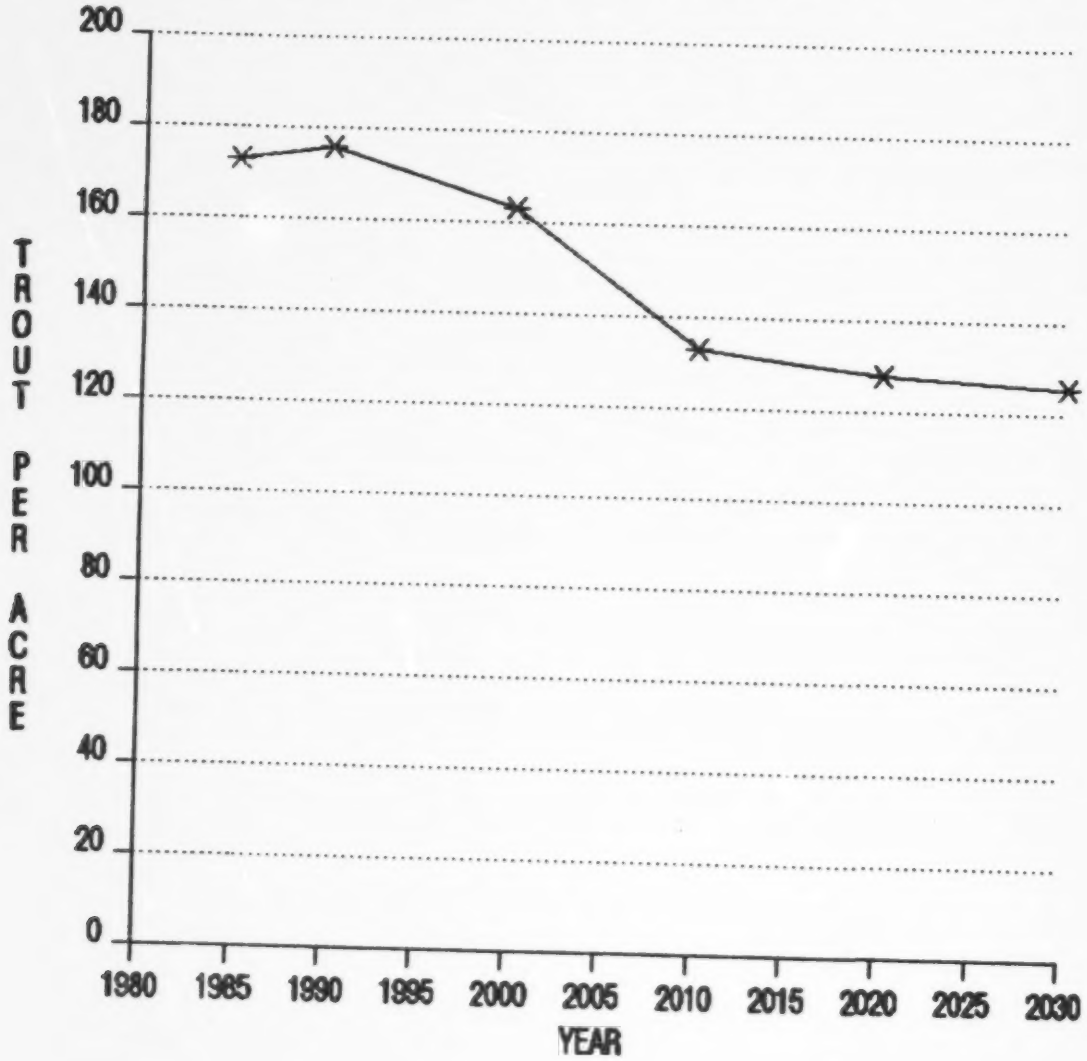
Although the decline of hardwood acres over the projection period is small, the age structure will change dramatically, resulting in a large decline in old-age hardwood acres in cold-water areas where hardwoods dominate the landscape. Regenerated hardwood stands begin to show up in the middle age class by 2020; however, none reach old-age status over the projection period (Figure 6.2). Trout density declines over time because high trout densities are associated with high acreage of old-age hardwoods. Human land use increases over the projection period and contributes to the degradation of trout habitat and trout density.

The objective of the fish analysis was to provide results from which planners and policy makers could assess the possible impacts resulting from changes in land use and timber management activities. In the context of the multiresource framework this analysis represents an initial effort to incorporate other resource considerations quantitatively into the traditional single resource analysis. The analysis discussed here represents a first generation effort. Now that the framework has been specified and applied, future research can incorporate a more detailed representation of the complex relationships between fish and the land and water resources that affect fish.

NOTES

1. Currently with the Forest Service, Fisheries and Wildlife, Blacksburg.

FIGURE 6.3: LIKELY FUTURE PROJECTIONS OF TROUT DENSITY[1]



[1] Trout per acre of trout stream in watersheds

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7

LAND MODELLING IN TACTICAL PLANNING: POTENTIAL USE AND A DECISION-CENTRED APPROACH

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ABSTRACT

Land modelling has proven to have considerable value in land evaluation and research. Modelling does, however, continue to struggle for acceptance at tactical levels in the land planning process. It is at this level that the realities of decision making intrude on what was previously a largely technical exercise. There is nevertheless considerable potential for the development of interactive systems using land modelling to aid and improve the tactical decision process.

This paper explores the need for, and potential of, land modelling at tactical levels. To exploit this potential fully, it is argued that a decision-centred approach is required, considering both the decision process and support requirements along with the technical components of a modelling exercise. In this regard emphasis is placed on the ways in which land modelling can aid and improve decision making aside from the traditional information products produced by models. To provide a practical context, LUPLAN, an interactive planning tool, and an illustrative tactical resource planning application are discussed.

INTRODUCTION

Land modelling is now becoming a useful and accepted component of land research and resource evaluation. It has become an important specialized management tool in several disciplines, from forestry to agriculture, as well as the foundation of information systems covering extensive geographic areas. Land modelling does, however, continue to struggle for acceptance at the tactical level.

Tactical planning involves the translation of strategic policies or objectives, like provincial policy statements and resource allocation targets, into spatial plans or specific policies. In Ontario, such agencies as Conservation Authorities and Regional Governments often find themselves confronted with tactical decision problems. When models are introduced at this level, the realities of decision making intrude on what was previously a largely technical, scientific, or somewhat abstract exercise. It is also at this level that one of the primary objectives of land modelling -- to aid and improve the decision process -- can no longer be ignored.

This paper addresses land modelling at tactical levels from the perspectives of a potential user. This discussion is developed in three stages.

1. The need for land modelling at tactical levels.
2. The approach required for effective integration of land modelling at tactical levels.
3. What can be gained.

The case is made that modelling should be applied at tactical levels and that successful application requires a decision-centred approach. If modelling is successfully placed within a decision support context at the tactical level, a number of benefits can be expected beyond the simple generation of an information product.

TACTICAL DECISION MAKING

Tactical decision making, as defined in the introduction, lies between strategic planning and operational measures. Decision making at this level is, when compared to strategic planning, often viewed as being relatively well-structured. Well-structured decisions involve problems which are well enough understood to be characterized as routine and repetitive, with a widely accepted interpretation and measure of success (Mason and Mitroff, 1981). While there is certainly a greater frequency of this decision type at tactical levels, it is a mistake to assume that this decision type dominates tactical planning. Such an assumption leads to the conclusion that decision support at this level should take the form of a simple information product, preferably with an explicit rating or choice preference.

Decision type at the tactical level is better characterized as semi-structured. In a semi-structured decision problem, there is a certain amount of strategic or policy guidance as well as sufficient information to define the nature of the problem (Keen and Morton, 1978). They do, however, also display many of the characteristics of poorly-structured or wicked problems (Mason and Mitroff, 1981). For example:

1. there are conflicting and competing interests creating a need for tradeoffs within the same value system,
2. there are dynamic and uncertain environments complicated by incomplete information,
3. the problem can be seen in different ways depending on circumstances and individual or group perspectives and as a result, there is no definitive or correct interpretation,
4. there is no single criteria system or rule to determine a correct outcome, and
5. there are social, organizational, and political dimensions which are influential.

This leads to the conclusion that semi-structured problems have sufficient structure for computer and analytical aids to be of value but intuition, value judgments and creative responses are still essential.

Wetland Planning as a Tactical Decision Problem

Wetland planning in Ontario can be used to illustrate a representative tactical decision problem. In this case, strategic guidance is provided by the Province of Ontario in the form of an evaluation system and guidelines for wetland management. The evaluation system consists of a scoring scale with points assigned to such values as size, hydrological function, and species composition (Ontario Ministry of Natural Resources [OMNR] and Environment Canada, 1984). Individual wetland complexes are assigned to a class based on their evaluation score. The related guidelines provide some direction for planning and state, in a somewhat permissive fashion, that provincially significant wetlands (generally Classes 1 and 2) should be protected through the local planning process (OMNR, 1984).

While all of this provides some policy direction, decisions left for the tactical level are anything but routine. Tactical planning agencies are left with such decision problems as:

1. what level of protection to provide Class 3 or 4 wetlands which may have considerable local or regional importance,
2. how to measure the direct and indirect impacts of any proposed uses on wetland values, and
3. how to evaluate competing resource uses like forestry, agriculture, or

aggregate extraction, in wetland areas.

Although these problems are possible to define and describe, they are complicated by competing interests, incomplete information, or poorly developed assessment techniques as well as political and organizational considerations.

Tactical Decisions and Modelling

This leads to the argument that modelling should be extended to provide support at tactical levels. Modelling should be designed in part with those planners, managers and other decision makers in mind that are trying to adapt strategic policies based on external information to their local tactical decision problems.

Currently, those involved find themselves handed the results of a modelling exercise completed by a federal agency or university and encouraged to view it as an integral component of their particular decision process. However, these information products rarely allow incorporation of local values, nor are they easy to sell to politicians or senior decision makers. As Jeffers (1981, p. 94) observed:

> Such people are not content to be told that a particular course of action is best because a mathematical model says so. It is, therefore, especially unfortunate that the mathematical models we would prefer to use present so little opportunity for investigation of their assumptions and constructions of their implications by the users of the results.

With the current support opportunities available through modelling and interactive computer systems, this need not be the case. This is especially true in that the type of semi-structured problems encountered at tactical levels are ideally suited for computer-based decision support. To begin to exploit these opportunities, the design process must take the nature and needs of tactical planning into account. The following section presents a decision-centred approach as a step in this direction.

A DECISION-CENTRED APPROACH

Given that the need to extend modelling approaches to provide support at tactical decision levels is accepted, some consideration should be given to how this is best accomplished. Initially it is important to recognize that the development and application of land resource planning models should be embedded in the wider context of the decision making process (Jeffers, 1981). To be effective in this context, a basic shift is required from specialized technical modelling or large-scale information systems to decision support systems.

The purpose of decision support systems (DSS) is to improve the effectiveness of decision makers (Sprague and Carlson, 1981). More specifically, decision support systems:

1. can serve a variety of decision types but are most effective where there is enough structure for computer and analytical aids to be of value but where judgment is an essential component of the decision process,
2. extend the range and capability of a decision maker's process to help them improve their effectiveness, and
3. create a supportive tool under the control of the decision maker which does not attempt to automate the decision process, predefine objectives, or impose solutions.

Decision support systems are designed to provide flexibility and the capability to explore decision problems and incorporate value judgments as well as facilitate important information management functions.

While decision support systems can take many forms, this paper deals primarily with interactive PC-based systems for spatial data analysis. These systems usually consist of data management components, models for

manipulation or data analysis, output, and an interactive dialogue component. DSS are most commonly aimed at those who support the decision process, such as middle managers or planners, but can occasionally be used by more senior decision makers (McGowan and Lombardo, 1986).

Decision Diagnosis

If land modelling is to become an effective component of decision support, then a decision-centred design approach is necessary. A decision-centred approach begins with decision diagnosis. Decision diagnosis is the act of defining the decision process and environment by examination and analysis. Two analytical questions have important implications for land modelling.

1. What type of decision environment is involved?
2. How is the decision arrived at?

The difficulty and complexity of the land modelling task depends to a significant degree on the decision environment. Figure 7.1 provides a simplified view of four types of decision environments. As the decision environment moves from Sector a to d, the conflict and complexity becomes more difficult to deal with. This is a reflection of the decision structure. The structure of problems associated with land modelling is a function of many factors including the number of competing uses and values, the quantity and quality of available information, and the nature of the decision environment. Models of decision making identify a continuum of decision types from well-structured to poorly-structured. As noted previously, most tactical decision problems fall somewhere in between.

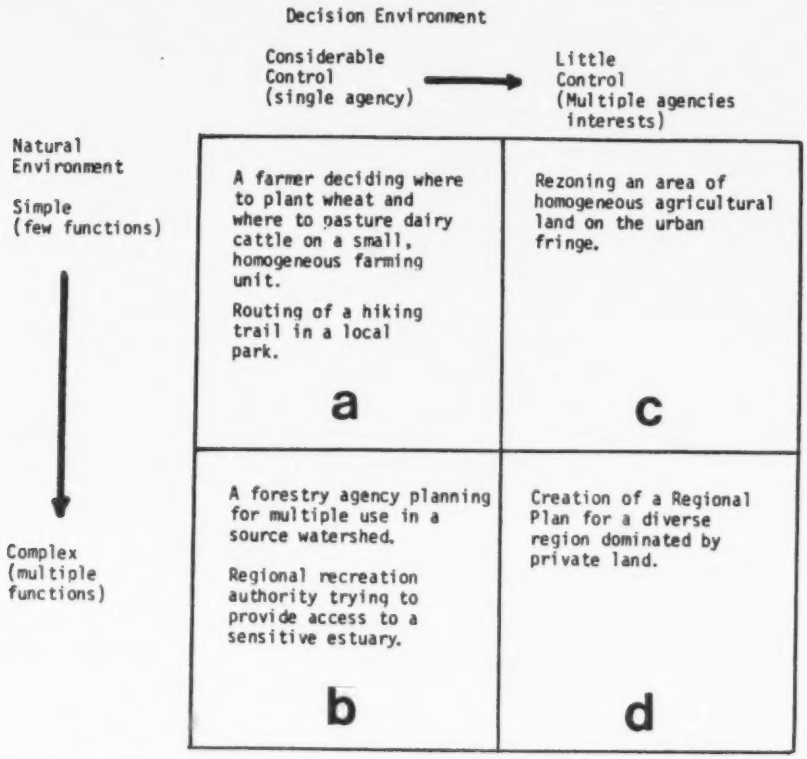
Decision structure has important implications for modelling. Different types of decisions have different information processing requirements and analytical needs (Bennet, 1983). A very well-structured decision may be amenable to an explicit, comprehensive analysis while poorly-structured problems would require more flexible and adaptive techniques.

The second important component of decision diagnosis is an understanding of the decision process or how a decision is made. It is, however, difficult to provide an explicit description of how many tactical decisions are made. A diagnostic approach simply recognizes that decision processes vary, with a variety of factors combining to influence the process. Briefly, an objective rational decision is often unattainable.

1. Decision making often involves incremental movement towards satisfactory choices. Rather than identifying an optimal solution, the process examines alternatives that offer different marginal combinations of values to discover a choice which is at least acceptable after only a moderate search (Keen and Morton, 1978).
2. Decision making often involves bargaining or negotiation. As alternatives are compared, bargaining occurs between individuals, government agencies, resource sector interests, and political factions in an effort to arrive at satisfactory policies.
3. Decisions are often made within, and as a result of, organizational environments. In these environments, decision making may depend on the hueristics and standard operating procedures within organizational units.
4. Decision making is often dominated by the political process. The process involves interactions between various actors, each with particular interests, priorities, constraints and power. Advocacy, power, channels of communication, and the rules of the political game become critical in the decision process.

Any given decision process could display one or all of these characteristics. Those involved in a modelling exercise will undoubtedly

FIGURE 7.1: A GRAPHIC ILLUSTRATION OF THE VARIOUS TYPES OF DECISION ENVIRONMENTS


Decision Environment
Considerable Control (single agency)
Little Control (Multiple agencies interests)
Natural Environment
Simple (few functions)
Complex (multiple functions)
A farmer deciding where to plant wheat and where to pasture dairy cattle on a small, homogeneous farming unit.
Routing of a hiking trail in a local park.
a
Rezoning an area of homogeneous agricultural land on the urban fringe.
c
A forestry agency planning for multiple use in a source watershed.
Regional recreation authority trying to provide access to a sensitive estuary.
b
Creation of a Regional Plan for a diverse region dominated by private land.
d

Adapted from Lang (1979)

encounter these realities during the design and use of their products.

Once decision diagnosis is complete, a modeller should have a much better understanding of how and why a model is to be used. The next challenge is to translate some of this awareness into design criteria.

Design Implications of Decision Diagnosis

Modelling cannot, of course, account for all of the realities of the tactical decision process. An attempt to provide a perfect fit between a model and a decision environment can paralyse the design process just as pursuit of scientific interests without examining how and why a model is to be used can lead to what Lang (1979) referred to as information degeneration. However, general principles can be derived from the decision process for use in the design process. The following four criteria are offered as representative examples.

1. The decision maker should have the ability to explore the decision problem.

As argued by Lock (1983, p. 160):

> Ultimately, the analysis has to be useful to decision makers and they have to feel confident about it. The presentation of a single best option does not always inspire this confidence. Strict optimization is less attractive than the ability to explore the problem. A major role for computer-based systems is the facilitation of manager-based sensitivity analyses and the ability to respond to "what if" questions. Decision makers acquire commitment to the solution by feeling both that they have some control over the solution and that they have contributed to its development.

Two types of exploration are envisioned. The decision maker or user would benefit from the ability to explore the problem itself, its dimensions and the interactions between its elements, and the range of possible solutions. A decision maker may also need to explore the implications of various alternatives or parameter values.

2. Flexibility is important if a model is to be an effective component of decision support for several reasons.
   a. It allows problem exploration. The "what if" questions can only be asked if the system is flexible enough to allow for the systematic manipulation of input and parameters.
   b. Users can rarely specify functional requirements in advance, nor can they always articulate what they need or want. Flexibility is required to allow some reaction-correction or iterative design.
   c. Variables in the decision environment change over time. These include changes in societal values, inputs required for land utilization, and the information available to actors involved in the decision. Flexibility is required to accommodate such changes without invalidating the complete evaluation.

   These observations lead to the need for two types of flexibility (Sprague and Carlson, 1981). The first level of flexibility provides the user with the means for creative problem solving. A particular decision can be explored by varying the components or operations within the model. The second level involves the ability of the system to evolve or accommodate new demands from users or changes in the decision environment.
3. A model should provide understandable or intuitively meaningful output. If the results are obscured in technical language, then effective use will be difficult.
4. Model based decision support systems can rarely be developed in one design cycle with fixed steps and well-defined boundaries. Rather, the design process should be one of adaptive evolution and iteration (Keen and Gambino, 1983). This usually involves supplying a small, flexible system, allowing users to react to the system, and then making any necessary changes. Within this process, a difficult tradeoff should be acknowledged. This involves the effort to support the existing decision process while encouraging more effective decision making. Just how far and how quickly to move towards innovative approaches must be decided. Keen and Gambino (1983) suggest that the first priority should be to support the existing decision process, and then slowly improve the process as user learning occurs.

These types of decision-centred principles have been promoted as important design considerations by a number of professionals involved in decision support. For example, Bozeman and Bretschneider (1986) argued that system construction must account for the special nature of the public sector decision process. They prescribed ten guidelines for the development of public management information systems including incremental/contingent planning approaches and the need to anticipate extra-organizational and vertical

linkages. There is clearly no shortage of principles to guide model or decision support system development using a decision-centred approach.

LUPLAN - An Interactive Planning Model

There are currently land modelling packages available which reflect some of the principles previously discussed and could form the foundation of a decision support system. One such package is the interactive PC-based system LUPLAN which was developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia (Davis and Ive, 1985). LUPLAN involves the construction and weighing of policy sets. A suitability score is assigned to predefined land units based on the policy weights and an evaluative formula written in BASIC and applied to data items stored for each unit. Policy sets, weights, evaluative formulas, and the information base can all be systematically changed to provide support for a variety of decision tasks.

To date, LUPLAN has been applied primarily in rural and conservation planning exercises. In these exercises, several decision support qualities have emerged. It does, for instance, depend on the intuition and judgment of users while providing an automated means to explore policy options and their implications on land use. McDonald and Brown (1984) commented that LUPLAN was transparent in that assumptions and values are easily isolated. They also found that the technique forces a decision maker to consider a wide range of factors involved in land suitability assessment. Finally, interactive use of LUPLAN allows a decision maker to explore the implications of different value profiles, the sensitivity of the system to value changes, and the areas of greatest potential land-use conflict (Miller, 1985).

While LUPLAN certainly has its disadvantages as well, it does serve as proof that decision-centred approaches can be put into practice. Once a model-based decision support system designed with a decision-centred approach is implemented at the tactical level, a number of benefits can be expected. The final section of this paper describes some of these potential benefits.

BENEFITS OF A DECISION-CENTRED MODELLING APPROACH

It is important to understand that in the tactical decision process, land modelling cannot be expected to provide a panacea in the form of an instant resolution or correct answer, nor should this be the objective. As stated previously, the goal is to aid and improve the decision process. Figure 7.2 is a very simple illustration showing some of the aspects of an ongoing decision process.

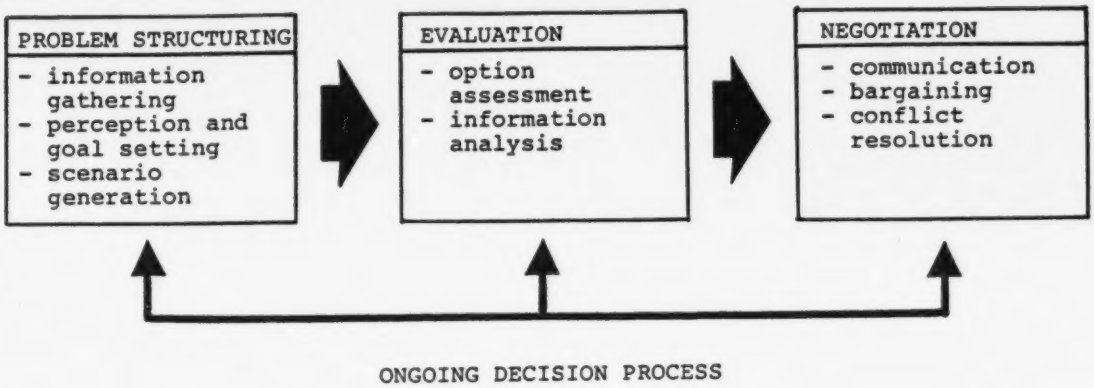
There are a number of ways in which a properly conceived and designed support system can aid and improve this decision process. Some of these have been introduced previously. Two examples are presented below to demonstrate the kinds of benefits which can be derived beyond the actual information product produced by the model. Within each example, the potential benefits of using LUPLAN to support tactical wetland planning are discussed to provide a practical context.

Individual and Organizational Learning

The first benefit is the potential for a support system to facilitate and encourage individual and organizational learning. As Hunt and Sanders (1986) argued, learning is both a fundamental descriptive feature and a normative objective of decision support system development. Learning can occur when a model:

1. makes a decision maker or user think explicitly about utilities and tradeoffs, thereby improving problem structuring. Use of a LUPLAN model to evaluate tactical wetland planning strategies would require the construction and weighing of a policy set. This would force those involved in the decision

FIGURE 7.2: A SIMPLIFIED SCHEMATIC OF THE DECISION PROCESS



process to think about the basis for making wetland preservation decisions as well as the relative importance of the components which form the evaluation system,

2. allows user-based sensitivity analysis and exploration. In being able to test the implications of decisions, a decision maker can explore a wider variety of options and improve the search function. Use of a LUPLAN model would allow various policy weights and criteria to be tested to explore their implications for wetland planning. Greater weight could, for example, be given to the presence of rare species and the resulting output examined to determine perservation priorities from that perspective,
3. encourages organizational learning and communication through coordination and information sharing. The process of constructing a LUPLAN model would require the sharing of information to develop the database and rating codes. It may also be necessary to involve several organizations in the construction of the policy set, and
4. improves the functional knowledge of those involved. The process of building and using a LUPLAN model would require those involved to develop a good understanding of the wetland evaluation system, thereby improving their functional knowledge of wetland values and their environmental role.

Negotiation

Decision making in tactical planning is rarely an individual activity. In most cases, bargaining or negotiation occurs at some point in the decision process. Fisher and Ury (1981) recognized the importance of negotiation and developed a framework for principled bargaining. This framework included such principles as:

1. establishing and focussing on an objective criteria,
2. focussing on participant's interests, not positions,
3. understanding both your own and other's values and their implications, and
4. participating as a well-informed individual.

Any contribution that a model-based DSS can make towards improving the negotiation component of tactical decision making can therefore be very important (Jeffers, 1981).

Models can in fact help to facilitate principled bargaining. Jarke (1986) discussed this potential and suggested that multiperson

decision support knowledge sharing can be used in negotiation if certain design requirements are met. Several of these requirements, like the ability to test and explore the underlying assumptions of a model, are very similar to the decision-centred design principles reviewed previously.

If a decision support system for tactical wetland planning was constructed around a LUPLAN model, those involved in bargaining could find that:

1. the model provides a common language and, through the policy set, some objective criteria,
2. participants would have to focus on interests in order to operate the model. Rather than expressing a position, the model requires consideration of policy weights which essentially express the interests of those involved,
3. it would be possible to test the implications of the values and interests held by other participants in the process, and
4. potential compromises could be quickly explored and tested.

These are just a few of the ways in which modelling can assist principled bargaining.

The primary message inherent in these examples is that the model user may find that the expected or unexpected benefits related to the decision process are equally, and possibly more, important than the information product initially produced as model output. This is an important point to remember when a model is being designed and constructed.

CONCLUSION

In conclusion, land modelling can play an important role in tactical planning. To exploit this potential fully, models should be constructed as decision support systems using decision-centred design approaches. In this context, the contribution of modelling can be seen in such benefits as the encouragement of learning and improved negotiation, rather than the generation of a single "correct" or optimal answer.

NOTES

1. Currently with the Regional Municipality of Niagara, Thorold.

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8

DEVELOPMENT AND APPLICATION OF "ENVIRONOMIC UNITS": HYBRID MAP UNITS DESIGNED TO INTEGRATE ENVIRONMENTAL AND SOCIO-ECONOMIC DATA FOR LAND MODELLING

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ABSTRACT

Political attitudes concerning the state of the environment have changed dramatically during the last two decades. Whereas in the past most politicians focussed their attention on the economy, today it appears that many suspect that a healthy environment leads to a healthy economy. Consequently, the need to integrate environmental and socio-economic data to enable comprehensive environmental assessments is becoming progressively more important. This study presents a simple and economical concept facilitating the integration and application of both types of data.

"Environomic unit" boundaries were created by combining well-established socio-economic map units (census divisions) with land resource map units (ecoregions) to form a hybrid framework which can accommodate both types of attribute data. The environomic map units were used to apply an existing model which described "known relationships" and to assist in developing an hypothesis (model) suggesting new potential relationships. These modelling scenarios were aimed at testing the utility of environomic units and were completed for a study area encompassing the prairie provinces. The major themes addressed include the potential of wind erosion to impact agricultural lands and labour force, and possible links between fertilizer and herbicide application and cancer mortality. The hybrid maps proved to be a simple, economical and useful concept for integrating environmental and socio-economic data for developing and applying land models.

INTRODUCTION

Purpose

This project aims to develop hybrid map units designed for integrating environmental and socio-economic data for the purposes of land modelling. Examples are provided demonstrating the potential utility of these for integrating, analyzing, and presenting both types of data. Environomic units is a term derived for this study by combining the terms *environ*mental and ec*onomic* to describe the hybrid derived by merging environmental and socio-economic map units.

The study area chosen for the pilot study consisted of the prairie provinces of Canada (Manitoba, Saskatchewan and Alberta), which represent diverse landscapes (mountains, hills and plains) as well as socio-economic profiles. An input scale of 1:7.5 million provided a sufficient level of detail to present national overviews and conforms to the current and anticipated national modelling initiatives of

the Lands Directorate.

Problem Definition

The Need to Integrate Environmental and Socio-Economic Data

During the last two decades, the Lands Directorate, in collaboration with other federal, provincial and territorial agencies, has dedicated much time and effort to establishing land resource databases to assist planners and managers in developing pro-active land management strategies and to plan effectively the use of Canada's land resources. Whereas efforts initially focussed on the acquisition, compilation, and classification of land resource data, the emphasis is now on the use or application of these data to provide useful information to environmental policy and decision makers. Based on preliminary attempts within the Lands Directorate to use these databases to address current issues, it was clear that land data alone are not always adequate. In fact, many planning issues cannot be fully addressed without considering the socio-economic aspects. For example, environmental impact assessment is of limited value without understanding the socio-economic ramifications of a proposed activity. The quantification of "resources at risk" and the process of "environmental cost accounting" are highly effective in communicating the socio-economic implications of current and alternative policies (e.g., number of jobs that may be lost due to environmental degradation). In short, two predominant concerns commonly emerge in most planning exercises. Environmentalists focus their attention on predicting the adverse environmental effects of a proposed activity. Advocates or promoters of the activity will predict the socio-economic benefits. Invariably, both considerations must be carefully assessed before a decision is made to permit or restrict any proposed activity.

Currently Used Integration Alternatives

Because environmental and socio-economic data are collected using different map (geographic) units, integration of them is difficult. Past attempts have focussed on two major approaches:

1. the use of a Geographic Information System (GIS), and
2. integrating all data into either environmental or socio-economic map units.

Integration Using a GIS: The complete integration of different map coverages, including their descriptive attribute data, can be achieved through the use of a GIS. Poiker and Crain (1985, p. 1) define a GIS as:

> ... a system designed to store and manipulate data which relate to locations on the Earth's surface. A GIS must handle two distinctive types of data -- graphical (spatial or geo-coded) data consisting of the geometric entities of points, lines and areas and attribute data, the non-graphical items which describe the geometric entities. Because GISs are used to manipulate extremely large quantities of data, most modern GISs employ computer technology. Typically a GIS will have three components: (1) input and editing; (2) data manipulation; and (3) output and display. [Sample GIS manipulation functions include:] ... the changing of map projection, contouring of map data, determining the intersections of overlapping polygons [topological overlay], data selection and generalization, registering and superimposing various data sets, and a whole range of statistical analyses.

Most GISs provide the capability to overlay maps to create a composite map retaining the respective attributes. Such systems are extremely useful for integrating different environmental and socio-economic data themes (Kerr et al., 1985; McCuaig and Manning, 1982); however, access, cost, complexity, and time may prove prohibitive in many cases. GIS are expensive and therefore are not widely available, they are difficult to use and thus require trained personnel and the integration of different map themes commonly requires the user to follow a series of complex procedures which can be time consuming.

Integration Using Either Environmental or Socio-Economic Map Units: The second method includes integrating socio-economic data into environmental map units (Bird and Rapport, 1986; Statistics Canada, 1978 and 1986) or integrating land resource data into socio-economic map units (Laut et al., 1980; Lynch-Stewart, 1986; Statistics Canada, 1986). All environmental and socio-economic map units in these examples consist of "fixed" map areas or polygons which do not change (theoretically) over time. The use of fixed map units enables the comparison of data over time (time series), and in some cases will facilitate data acquisition by providing procedural consistency.

An example of integrating land resource data into socio-economic map units is when land resource characteristics are represented as a per cent area or as the dominant feature within socio-administrative map units, such as census divisions. Planners and managers are generally uncomfortable with this concept, feeling that natural phenomena should not be represented within artificial man-made boundaries (Friend, 1979). The alternative of integrating socio-economic data into a land resource framework can also be problematic, as important socio-economic distinctions can no longer be readily discerned or monitored. For example, two census divisions (counties) characterized by the same land capability for forestry, may be used and managed quite differently according to respective regional policies. However, the effects of these different policies could not be detected if the data describing the effects (gathered by census divisions) were integrated into a land resource framework. In summary:

> The development of an environmental statistical data base requires the establishment of the appropriate spatial entities. The current use of administrative boundaries is on the whole unsatisfactory for describing environmental transformation. The [chosen] spatial units should be based in essence on a compromise between "idealized" scientific criteria and the socio-political criteria, including "arbitrary" administrative boundaries. In other words the spatial entities must accommodate both the decision making space and the natural process space (Friend, 1979, p. 117).

The Need for Compromise Map Units

Environment Canada is currently committed to producing "State of the Environment" reports at regular intervals. As part of this initiative, a Stakeholder Group on Environmental Reporting was recently established to consider improvements to environmental and resource data collection and reporting in Canada. As outlined in their report, one of the major shortcomings of current environmental data and reporting in Canada is that:

> There is no comprehensive framework which describes the scope or extent of the interactions between human activities and the environment, upon which an environmental reporting system could be based and which would provide a better public understanding of these interactions (Stakeholder Group on Environmental Reporting, 1986, p. 10).

The report suggests that a functional framework must enable:

> ... the economy and the environment [to] be viewed as one complete system. This is necessary first to demonstrate the interactions between human activity and environmental impact, and second to insure that collected environmental data cover all the relationships and feedback effects that link human activity, environmental impact, and changes in health or resource base. A framework is necessary to define the scope of these linkages between the economy and the environment, and to help understand these linkages (Stakeholder Group on Environmental Reporting, 1986, p. 14).

Similar needs were reflected in the United Nations Educational, Scientific, and Cultural Organization (UNESCO) program Man and the Biosphere, which aimed "... to "build a research bridge" between ecological, economic and social sciences as well as to elaborate a methodology for linking ecological processes

and socio-economic phenomena with each other" (Brouwer, 1986, p. 4).

Similarly, the Commonwealth Scientific and Industrial Research Organization (CSIRO), in conjunction with the Australian Department of Science and Environment, established the Australian Environmental Statistics Project aimed at developing "... a practical framework for the organization of environmental statistics and ... to provide through this framework, a means of integrating assessments of economic and social impact of environmental policies with assessments of the environmental impacts of economic policies" (Laut et al., 1980, p. 1).

As these examples suggest, the need for a compromise framework which enables the economy and the environment to be viewed as a complete system is well documented.

Environomic Units as a "Compromise" Approach

The research presented here suggests a third "compromise" alternative which is simple and economical relative to a GIS and is more comprehensive and detailed than just environmental or socio-economic map units. It consists of combining well-established socio-economic map units with standardized land resource map units to form a hybrid which can accommodate both types of attribute data.

Models

As stated above, this project aimed to develop hybrid map units for integrating environmental and socio-economic data for land modelling. Models are effective tools for addressing specific issues in a systematic way. Model definition, characteristics, types, and utility are discussed below.

Definition

The term "model" is widely used and is becoming increasingly popular in various disciplines. This widespread use of the term has likely contributed to the variety of meanings associated with it. A literature review reveals that a clear, concise definition is not easy to obtain. For example, in **Models in Geography** (Chorley and Haggett, 1967), the authors explain that a model can be a theory, a law, an hypothesis, or any other form of structured idea. In fact, the only element which distinguishes these terms from one another is the degree of probability with which they can represent or predict reality. The degree of probability (level of error tolerated) required to distinguish between these terms remains unclear.

A model is thus a simplified representation of reality which presents significant features or relationships in a generalized form. Models are selective approximations in that they do not include all associated observations or measurements. A good model should therefore filter out incidental detail so that fundamental aspects of reality remain (Chorley and Haggett, 1967).

Major Characteristics of Models
(Based on Chorley and Haggett, 1967)

Models are selective approximations. A model must be simple enough for manipulation and understanding by its users, representative enough in the total range of implications it may have, and yet complex enough to represent accurately the system under study. Because models are different from the real world, they are analogies.

Models are structured. Phenomena are studied in terms of their connections or interrelationships.

Predictive models can be suggestive. In fact, such models are commonly evaluated according to their predictive capability. As such, models are often termed as "speculative tools".

Predictive models should be replicable in the real world. For example, the relationships identified by the model should be true (all

else being equal) in different applications.

Types of Models

Because models are used in such a wide variety of contexts, it is difficult to define even broad types of usage. One major division is between descriptive and predictive (normative) models. Descriptive models are concerned with describing the real world, such as scale models, maps, series of equations, or some other analogues (Morgan, 1967); predictive models are what might be expected to occur under certain conditions. Both are used to operationalize a theory, as a guide to the derivation of testable hypotheses (Johnston, 1983). Jeffers (1972) has suggested a third major category of models called decision models, which suggest certain courses of action or response under specific circumstances. For example, such a model might represent the recommended courses of action for each possible outcome of a certain event. In a sense, they might be viewed as structured recommendations used in conjunction with descriptive and (more likely) predictive models. Jeffers emphasizes that many models can fall into more than one of the above-mentioned categories, or move from one category to another in the course of an investigation.

The model categories mentioned above can be further divided into many other subcategories, which are usually named according to the dominant characteristic of the model. For example, models can be classed as static (steady state) versus dynamic; deterministic versus stochastic according to the degree of probability associated with their predictive capability; holistic versus reductionist according to their level of detail, etc.

Utility of Models

Models primarily help researchers to understand reality better. This knowledge or understanding should in turn influence or guide decision makers. Manning (1988, pp. 3-4) suggests that modelling procedures are used because they aid us to:

1. understand better what is happening,
2. fill specific information gaps,
3. demonstrate our understanding more effectively, or
4. exert influence on the decisions of others.

Models also encourage researchers to organize their concepts and ideas and to state their assumptions explicitly.

DEVELOPMENT OF ENVIRONOMIC UNITS

Map Units

Environomic unit boundaries were created by combining well-established socio-economic map units (census divisions) with land resource map units (ecoregions) to form a hybrid which can accommodate both types of attribute data. Ecoregions and census divisions are similar in terms of:

1. the total number of units for Canada,
2. the average size of map units (areal extent),
3. the suggested map scales of the units, and
4. the user acceptance of the units.

Both sets of units are briefly described below.

Census Divisions

Statistics Canada uses a range of map units referred to as "census geostatistical areas" which are hierarchical and can be used to present the same data and information at different scales or resolutions (Table 8.1).

The term census division refers to "... counties, regional districts, regional municipalities, and other similar entities defined by provincial authorities" (Statistics Canada, 1982a, p. 8). They are the most commonly used socio-economic reporting units for national overviews

TABLE 8.1: GEOSTATISTICAL UNITS, ASSOCIATED MAP SCALES, AND NUMBER OF MAP UNITS COVERING CANADA

GEOSTATISTICAL UNITS	ASSOCIATED MAP SCALES	NO. OF MAP UNITS COVERING CANADA
Province/Territory	1: 5,000,000 to 1:15,000,000	12
Census Division	1: 2,000,000 to 1: 7,500,000	266
Census Consolidated Sub.	1: 2,000,000 to 1: 7,500,000	2,545
Census Subdivision	1: 500,000 to 1: 2,000,000	5,710
Enumeration Area	1: 5,000 to 1: 500,000	41,197

Source: Lefebvre, 1986 and Statistics Canada, 1982b

of Canada. Statistics Canada provides a diverse range of data for Canada's 266 census divisions (Statistics Canada, 1982b).

Ecoregions

Ecological Land Classification (ELC) is a conceptual approach to integrating and classifying ecological data into map units based on the natural terrestrial ecosystems. The ELC uses fixed map units to describe areas which are ecologically uniform at appropriate map scales. These units are described in terms of their geology, landforms, soils, vegetation, hydrology, wildlife and climate and have been delineated for a variety of scales and geographical extent. Table 8.2 summarizes the ELC land unit names, corresponding map scale, and the number of map units covering Canada.

Members of the Ecological Research and Integrated Programs Division, have recently completed an ecoregion coverage for all of Canada. As indicated in Table 8.2 they are used at map scales of between 1:3 million and 1:7.5 million and by definition are areas of land which are characterized by a distinctive regional climate as expressed by vegetation.

The ELC approach of using fixed map units for reporting environmental data is a relatively new concept and has not been extensively utilized relative to census geostatistical units. The most visible application is the use of "ecozones" in the State of the Environment report (Bird and Rapport, 1986). Ecozones, however, are much too broad and general to address most land resource issues. Ecoregions, which number approximately 325 for the country, appear to be the most compatible with census divisions in terms of areal extent, and the number of polygons covering Canada.

Methods

Environomic units for the prairie provinces were derived by manually overlaying the census division and ecoregion coverages. The result consisted of a composite map with newly created polygons (illustrated in the top map of Figure 8.1). The two other maps in Figure 8.1 are shaded so that the original ecoregion and census division components are easily discernible within the environomic units.

Elimination of "Line Weave"

A common problem when overlaying two or more maps is when boundaries or portions of boundaries with similar spatial distributions "weave" in and out of each other. The resultant small polygons are referred to as "line weave" or "sliver" polygons. Such polygons within a given tolerance (3 mm^2 at a scale of 1:7.5 million) were eliminated by

TABLE 8.2: ELC MAP UNIT NAME, ASSOCIATED MAP SCALES, AND NUMBER OF MAP UNITS COVERING CANADA

ELC UNITS	ASSOCIATED MAP SCALES	NO. OF MAP UNITS COVERING CANADA
Ecozone	1:7,500,000 to 1:20,000,000	15
Ecoprovince	1:5,000,000 to 1:10,000,000	*1
Ecoregion	1:3,000,000 to 1: 7,500,000	325
Ecodistrict	1: 250,000 to 1: 1,000,000	5,395
Ecosection	1: 50,000 to 1: 125,000	*
Ecosite	1: 10,000 to 1: 25,000	*
Ecoelement	1: 2,000 to 1: 5,000	*

[1] National coverages for these units are not yet completed

Source: Rubec and Wiken, 1982

using one common boundary. In all cases, the census division boundary was used as the common boundary. Census divisions are geostatistical boundaries which are precisely delineated according to political jurisdictions. Ecoregions, on the other hand, are subjective approximations of natural terrestrial features.

Linking Attribute Data to Environomic Units

Each environomic unit was given a unique identification number consisting of:

1. a two-digit province code,
2. a two-digit census division code,
3. a two-digit ecoregion code, and
4. an alphabetic character if the three previous digits did not form a unique identification number.

As such, ecoregion or census division data can be easily linked to their respective map units.

APPLICATION OF ENVIRONOMIC UNITS

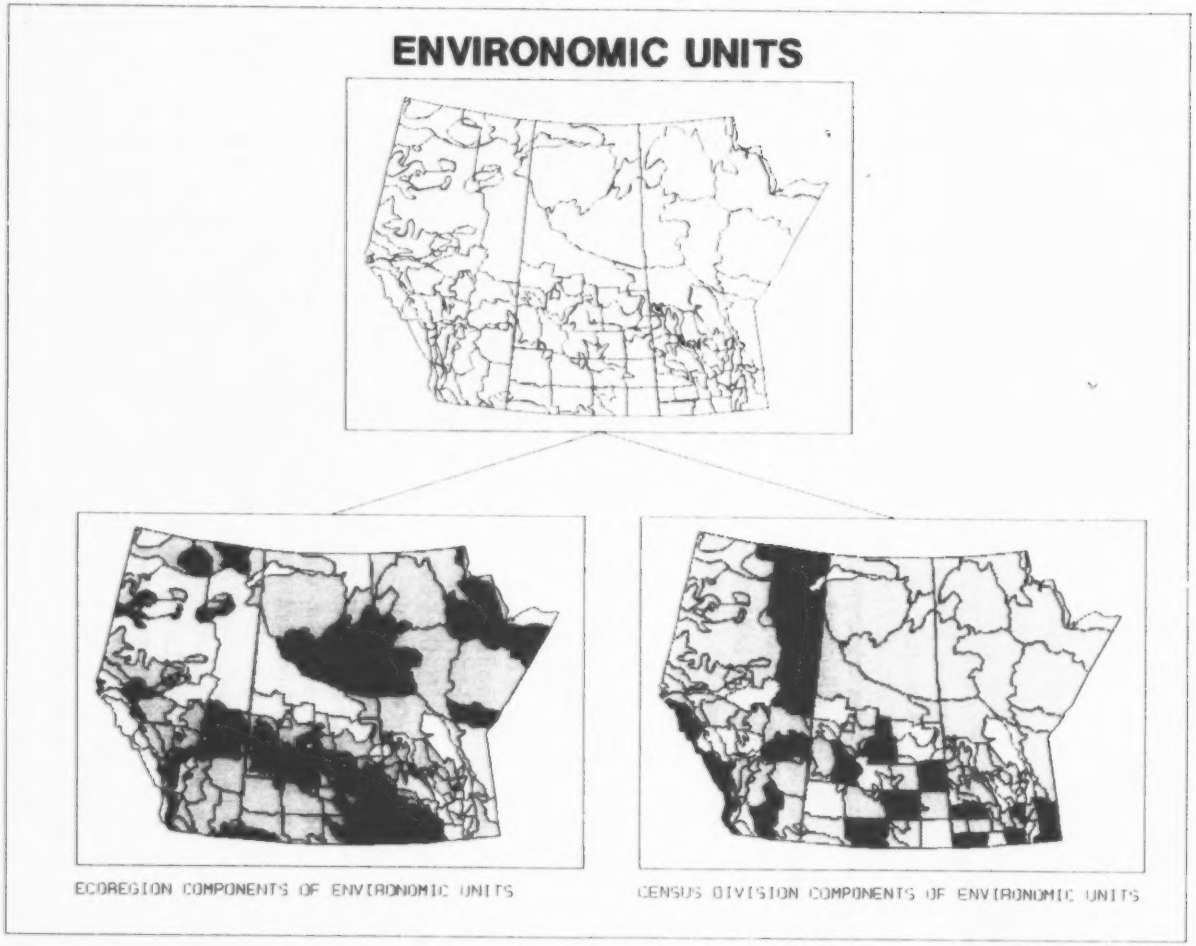
Computer-Assisted Cartography

Once environomic units were coded and quality assured, they were digitized and entered into a database to facilitate various modelling scenarios. All analysis and mapping was performed using the GIMMS computer-mapping package residing on a Data General MV 6000 minicomputer. Computer-mapping packages are commonly confused with GISs which are primarily designed to integrate (using an overlay capability) and manipulate different graphical and attribute data sets. While some computer-mapping packages can manipulate attribute data, they are not designed to integrate different graphical data sets. As such computer-mapping packages are ideally used with fixed map units such as census divisions where only the attribute data vary. Environomic units are designed to integrate ecoregion and census division data without using a GIS overlay capability. As seen in the section above, the development of units consisted of completing the overlay process manually.

Choropleth Mapping

All maps presented in this section are choropleth maps, which use variable shading gradients to help identify patterns or trends over a given area. Discrepancies or anomalies above or below the norm are easily identified by assigning poignant colours to extreme class intervals. Choropleth maps require

FIGURE 8.1: ECOREGION AND CENSUS DIVISION COMPONENTS OF ENVIRONOMIC UNITS



ratio data (e.g., percentages) for variables which are demographically related (e.g., socio-economic data). Also, when using the choropleth mapping technique, a value assigned to a specific spatial unit is assumed to be evenly distributed throughout the unit.

Class Intervals -- Relative Ratings

In the following examples, a number of maps are compared to identify potential risk areas and suggest possible relationships between themes. Consequently, a consistent methodology must be used to map each theme.

Equal class intervals were used for all maps. They are derived by taking the maximum value (recorded in the current data set) of the variable in question, minus the minimum value and dividing by the number of classes desired. As such, the term "relative ratings" indicates that values in "high" or "low" classes are high or low relative to all other observations in the study area.

Attribute Data

Eleven environmental variables (by ecoregion) describing climate, soils, land cover and topology as well as 21 socio-economic variables related to health, labour force, education, income, employment and agricultural practices were included in the database. These were chosen based on availability and their suitability in addressing current priority issues within the study area.

Analysis

Analytical Approaches

In applying models which describe "known relationships" or in attempting to develop models which identify "new relationships", researchers generally make use of what is known as the scientific method. Two main paradigms ("schools of thought") can be identified in the scientific method: the inductive and deductive approaches, or modes of explanation (Norcliffe, 1977). An inductive approach takes a set of unordered facts, analyses their characteristics, derives some order from the facts and thereby a model can be developed. A deductive approach is applied when a model (hypothesis) is known, and is tested or applied using sample observations. In theory, the two approaches are separate; in practice, however, they are interconnected and cannot be applied exclusive of each other since preconceived notions of relationships assist in inducting research, while prior experiences with data often contribute in deductive research.

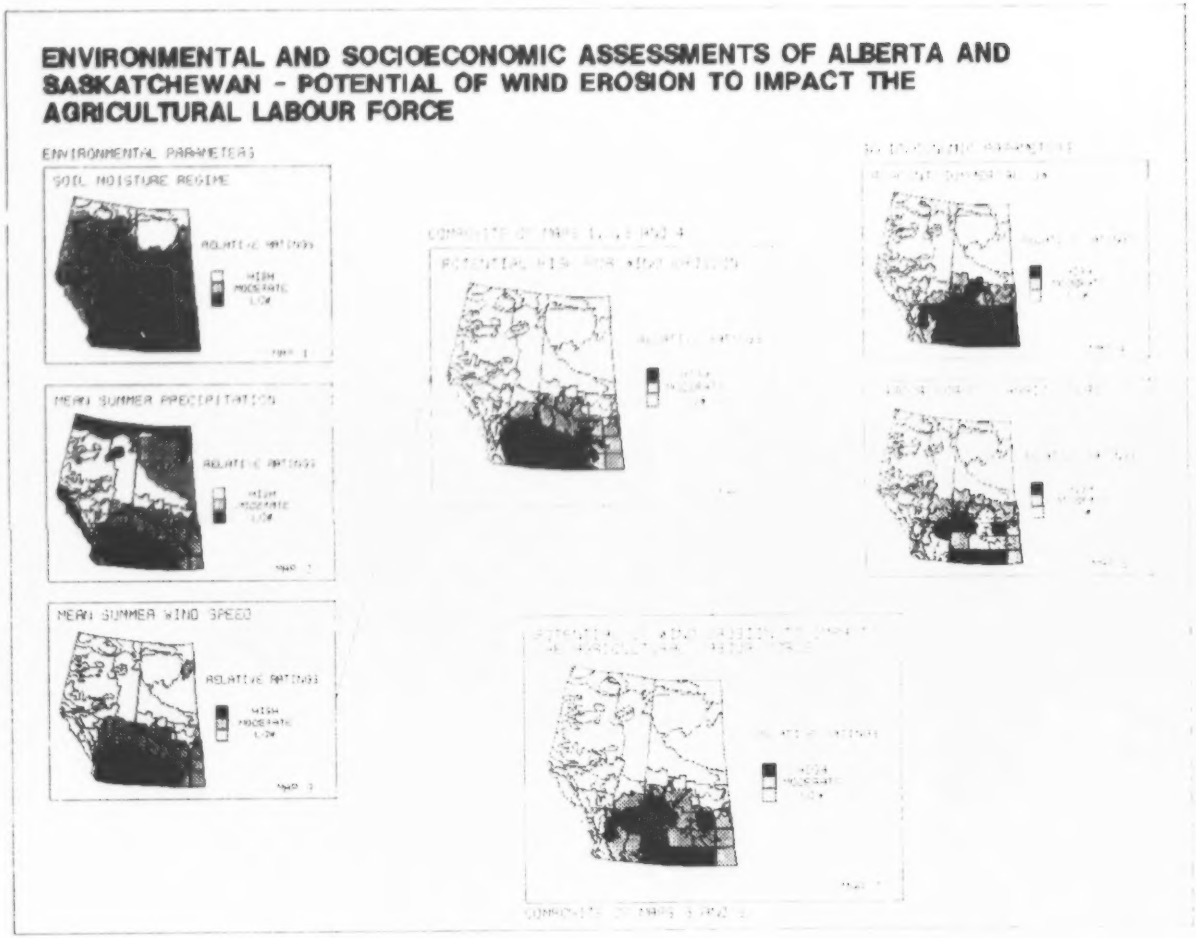
Both approaches were used in the following examples. For instance, one approach consisted of mapping different environmental and socio-economic variables individually to look for spatial distribution patterns. One such pattern which occurred served to generate an hypothesis (develop a model) which warrants further investigation. The other example applied an existing model using the environomic units to facilitate the integration, analysis and display of data.

Assessments of Potential Land Degradation Due To Wind Erosion

Recent figures suggest that losses from soil degradation in the prairie provinces now exceed $1.0 billion annually (Science Council of Canada, 1986). Wind and water erosion, which "reduce the organic matter content of soil, weaken its structure, diminish its water-holding capacity, and lower productivity" (Science Council of Canada, 1986, p. 9), are the most widespread forms of soil degradation in Canada. Although erosion is a natural process, agricultural practices can significantly affect its occurrence. For example, the loss of topsoil through wind erosion can be greatly increased through summerfallowing, excessive tilling, or failing to leave crop residues or cover crops in place. The model presented in Table 8.3 includes environmental conditions (by ecoregions) and cropping practices (by census divisions) which tend to augment the potential for wind erosion (Coote et al., 1981).

Figure 8.2 illustrates the result of applying the model in Table 8.3 to the Alberta and Saskatchewan portion of the environomic

FIGURE 8.2: POTENTIAL RISK FOR WIND EROSION AND ITS POSSIBLE IMPACT ON THE AGRICULTURAL LABOUR FORCE


ENVIRONMENTAL AND SOCIOECONOMIC ASSESSMENTS OF ALBERTA AND SASKATCHEWAN - POTENTIAL OF WIND EROSION TO IMPACT THE AGRICULTURAL LABOUR FORCE
ENVIRONMENTAL PARAMETERS
SOIL MOISTURE REGIME
MEAN SUMMER PRECIPITATION
MEAN SUMMER WIND SPEED
RELATIVE RATINGS
HIGH
MODERATE
LOW

Note: Wind erosion is brought about by a combination of environmental variables and man's activities through agricultural practices. This illustration identifies areas with such conditions and predicts the potential of wind erosion to impact on the agricultural labour force.

TABLE 8.3: MODEL USED TO DETERMINE AREAS POTENTIALLY AT RISK TO WIND EROSION

AREAS POTENTIALLY AT RISK TO WIND EROSION =

Areas which are characterized by:

Low Precipitation	AND
Low Moisture Regime	AND
High Average Summer Wind speed	AND
High Per Cent Summerfallow	

database. The conditions of low soil moisture (Map 1), low mean summer precipitation (Map 2) and high mean summer wind speed (Map 3) combine in certain areas to allow a situation of high risk for wind erosion to develop. These conditions, combined with the cropping practices of summerfallowing (Map 4), which leaves farmland exposed without vegetative cover during the growing season, can further increase the risk of soil erosion. The environomic units which were characterized by all of these conditions are represented as the dark polygons (high potential risk for wind erosion) in Map 6 of Figure 8.2. In this example, the environomic units facilitated the integration of data gathered by both ecoregions and census divisions to apply a model designed to identify areas at risk to wind erosion. Potential risk maps of this nature are useful to highlight areas where land resource planners and managers must take counter measures to avoid the problem.

Simply identifying areas with a high potential risk for wind erosion may not by itself have a great impact. Unless such scenarios can be linked to people's physical or economic well-being, they are not likely destined to get decision makers to take notice. In this case, those employed in the agricultural industry would likely be the first to be affected by wind erosion. Consequently, the map highlighting potential risk areas for wind erosion (Map 6) was combined with a map showing the distribution of those employed in the agriculture labour force sector (Map 5). The composite map (Map 7) illustrates the "hot spots" where the risk of wind erosion is high and the per cent labour force in agriculture is high.

Figure 8.2 demonstrates how environomic units can be used to integrate, analyse and display different data sets to address a particular issue. Many other iterations using the same or other data variables are possible. For example, if a researcher did not agree with the variables used to determine wind erosion risk areas, these could be easily changed provided the required data are available. The real challenge is predicting the socio-economic implications of wind erosion. This example simply attempted to identify the likely areas where the immediate socio-economic impacts would be greatest, that is, where a large percentage of the labour force depends on agriculture. More sophisticated models which can be used to predict the progressive and cumulative effects of different factors on agricultural yields and in turn the impacts on the regional economies could easily be applied using environomic units.

While the above scenario used data collected by either ecoregions or census divisions, it is possible to represent other data as a percentage of the total areal extent of each environomic unit or as the dominant feature within the unit.

In the mid-sixties, the Lands Directorate, in conjunction with other federal and provincial government agencies, undertook the Canada Land Inventory (CLI) which rated Canada's land based on its capability to support different renewable resources, such as agriculture, forestry, wildlife and recreation (Lands Directorate, 1978). The CLI study area covers roughly 2.6 million km^2 of southern Canada, providing reconnaissance-type information useful for land development planning at the municipal, regional, provincial

and federal levels of government. The inventory is commonly referred to by land resource planners and managers to assess the potential value of particular parcels of land. Because Canada does not have an over-abundance of prime agricultural land (usually defined as CLI classes 1, 2 and 3), decision makers must be careful not to lose this valuable supply to an irreversible land activity such an urbanization. Map 2 in Figure 8.3 shows environomic units which have CLI classes 1, 2 or 3 as the dominant capability. This was derived by manually overlaying environomic units with CLI agricultural capability. This map was combined with the wind erosion risk map (Map 1 in Figure 8.3) to assess the implications of wind erosion further. The dark polygons in Map 3 represent the prime agricultural lands which are threatened by a high risk of wind erosion. Figure 8.3 serves to identify wind erosion "hot spots" based on a second criterion (land capability) and to demonstrate the flexibility of the environomic units in integrating non-ecoregion or non-census division data to address an issue. Figures 8.2 and 8.3 provide planners and decision makers with a general assessment outlining areas which are valuable because of their agricultural capability and the labour opportunities they provide and which are threatened by wind erosion.

Spatial Distribution Patterns or Trends

Plotting various themes using the environomic framework can facilitate the identification of spatial trends, relationships, and anomalies or discrepancies which may not be apparent in tabular form. A recurrent theme throughout the Position Paper on Environmental Reporting (Stakeholder Group on Environmental Reporting, 1986) is the link between the environment and health. One field of research which attempts to link environmental conditions with physical well-being is medical geography. Environomic units are ideal for examining environmental characteristics (collected by ecoregions) which are possibly related to human health (collected by census geostatistical areas). A current (high profile) issue is the possible link between environmental conditions and the occurrence of cancer. Many scientists believe that cancer is in very large part an environmentally determined disease or group of diseases. The late Dr. George Oettle remarked that "... based on African experience, 80% or more of human cancer is environmentally determined and theoretically can be prevented" (Davies, 1979, p. 49). Studying the spatial distribution trends of environmental and socio-economic variables can lead to interesting hypotheses. Davies (1979) recounts that when the Ugandan Agricultural Department published a map of the distribution of banana trees in Uganda, it coincided with the distribution of cases of human bladder cancer. Davies also comments on a similar experience that he and his brother encountered: "... all the first cases of this Lymphoma (Burkitt Lymphoma Cancer) that we mapped came from the northern province of Uganda. Examination showed that by mapping the Lymphomas in this way, we had mapped the radioactive areas of Northern Uganda" (Davies, 1979, p. 49).

Plots of the environmental and socio-economic variables showed that mortality due to cancer of the digestive organs, fertilizer application, and herbicide application all had relatively high concentrations in southern Manitoba. Consequently, these concentrations were examined more closely in Figure 8.4 where cancer of the digestive organs (Map 2) was combined with fertilizer application (Map 1) and herbicide application (Map 3). Although the spatial distributions did not match perfectly (Maps 4 and 5), the same four polygons were flagged as high in both maps. This may only be reflecting a similar distribution between fertilizer and herbicide application or it may be reflecting some association between all three variables. Further investigations of such results are required to establish cause-effect relationships; however, trends or patterns of this nature can lead to formulating hypotheses. In this case, a similar spatial distribution trend is less significant because of the limited span of the study area. It would be preferable to verify if the pattern persists for the whole country before suggesting an hypothesis. Identifying trends of this nature could conceivably lead to major discoveries and

FIGURE 8.3: PRIME AGRICULTURAL LANDS THREATENED BY WIND EROSION

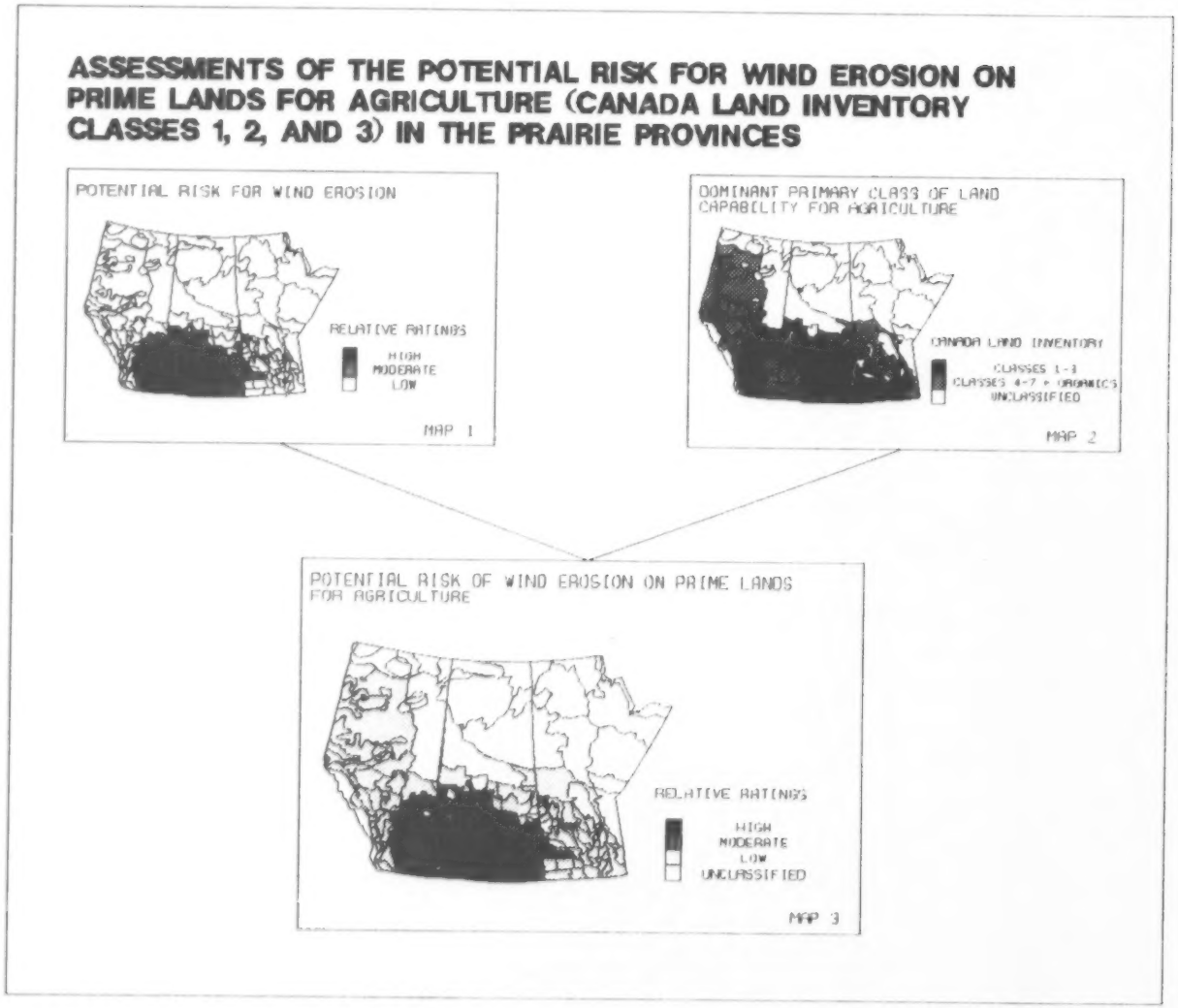
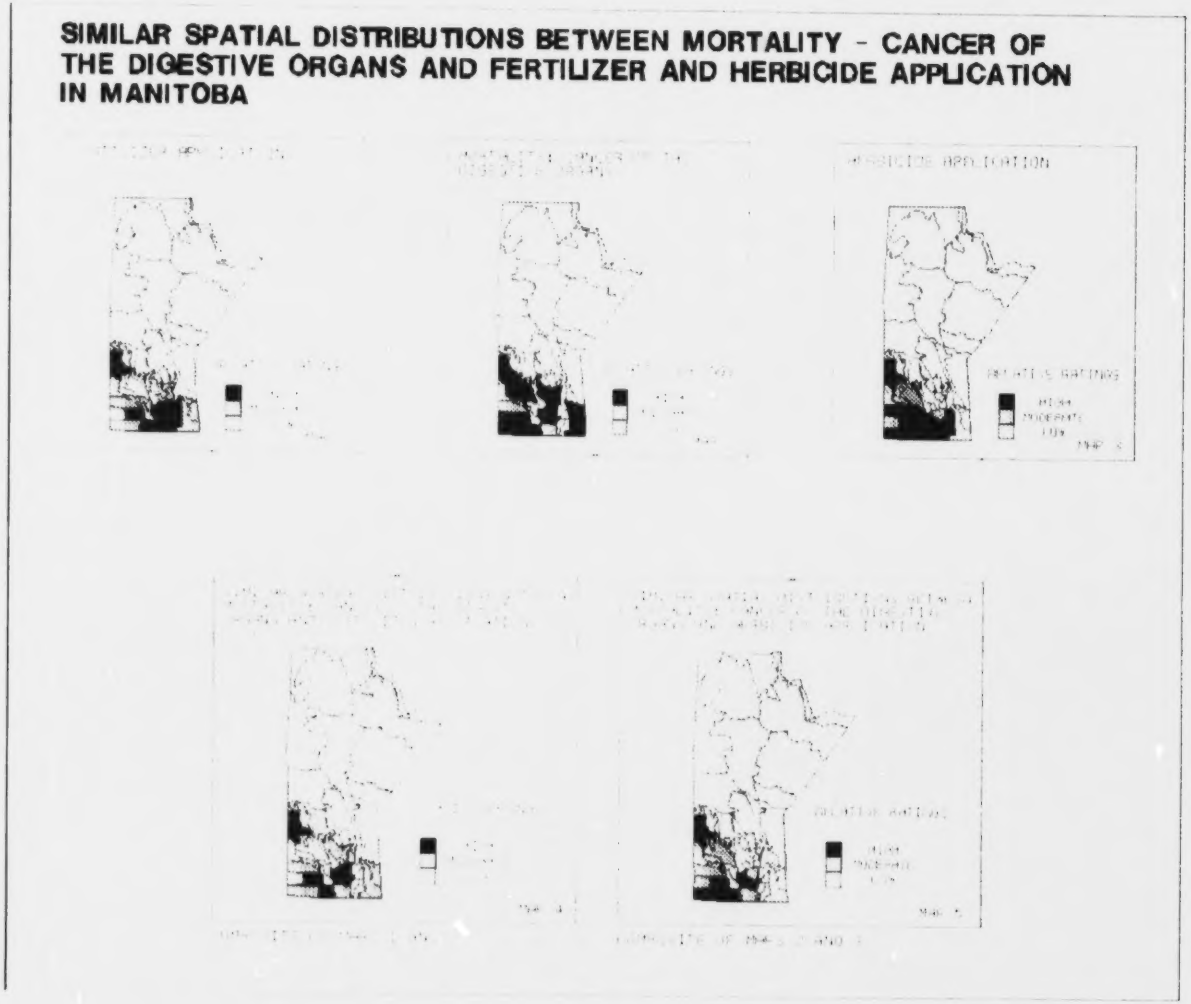


FIGURE 8.4: SIMILAR SPATIAL DISTRIBUTION PATTERNS BETWEEN CANCER MORTALITY AND FERTILIZER AND HERBICIDE APPLICATION


SIMILAR SPATIAL DISTRIBUTIONS BETWEEN MORTALITY - CANCER OF THE DIGESTIVE ORGANS AND FERTILIZER AND HERBICIDE APPLICATION IN MANITOBA

such research should be an important pursuit. In an age of automation, inductive research, which relies on much data processing, will likely become increasingly popular. The use of integrated map units such as environomic units will facilitate the process of linking environmental conditions to health.

As in the wind erosion scenarios, this analysis served as a screening exercise where potential "hot spots" were identified. An hypothesis suggesting the link between herbicide and fertilizer application and cancer mortality might be formulated as a result. Caution must be exercised when looking for similar spatial distribution trends. Such trends may be reflecting multiple, indirect, or delayed causes and effects and therefore only imply that the variables are associated (Friend, 1986). For example, many phenomena are multivariate in nature and a given variable may be influenced by many other variables, so that independent variable X may account for only a portion or none of the variation in variable Y. As such, similar spatial distributions can only serve to generate hypotheses which warrant further investigation. Such hypotheses or models, "... in the final analysis, are constructs for simplifying reality and often provide the basis for "real world" behaviour" (Friend, 1979, p. 118).

A major step facilitating this type of research will occur when other variables related to the state of the environment (e.g., air quality, acid deposition, toxic wastes, etc.) are available by ecoregion. It will then be possible to compare the spatial distributions of such environmental conditions with the occurrence of non-communicable diseases. Investigations of this nature can only increase our knowledge of the distribution and possibly the causes of such diseases and perhaps someday help develop appropriate control measures.

SUMMARY

Environomic units are a simple and economical concept designed to integrate environmental and socio-economic data. Accepting the premise that both types of data are required to address current environmental issues, three data integration approaches are possible. The first consists of describing all attribute data as a per cent area or according to the dominant feature within fixed map units. Alternatively, graphical and attribute data themes can be overlayed using a GIS to create a composite graphical and attribute data set. The third option, environomic units, is a compromise approach which incorporates strengths of the two other techniques such as overlay and fixed map units. In a sense, environomic units can be viewed as two standard data collection "funnels": ecoregions for environmental data and census divisions for socio-economic data.

Because environomic units are a hybrid of census divisions and ecoregions, both environmental and socio-economic data can be integrated without using a GIS overlay capability. In fact, the development of environomic units consisted of completing the overlay process manually. The intent was to integrate two well-established sets of map units which can accommodate a majority of available socio-economic and environmental data. In this way, the overlay process, elimination of line weave, quality assurance, etc. are completed once, and the composite result is subsequently used as the standard map units in the future. Integration using a GIS may still be desirable if other types of map units must be integrated.

The use of environomic units is comparatively cheap. A user can simply obtain Environment Canada and Statistics Canada data to use with the corresponding map units manually or with the help of a database management system and/or a computer mapping package. The hybrid units are not designed to compete with GIS technology, but rather to provide a simple and economical alternative. In fact, environomic units could complement GISs by providing "quick and dirty" overviews to determine whether a more sophisticated GIS study is required.

Finally, because environomic units retain the original census division and ecoregion

boundaries, they are more comprehensive and detailed than when all socio-economic data are integrated into ecoregions or vice-versa.

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PART 3
MODELS FOR ACID DEPOSITION IMPACT ASSESSMENT

9

ACID RAIN AND AGRICULTURAL PRODUCTION IN ONTARIO

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ABSTRACT

This paper describes the development of an analytical framework to assess the implications of environmental change for agriculture. The framework, which consists of three steps, is applied to estimate the impacts of acid rain on agricultural production in Ontario. The first step identifies the degree to which acid rain distribution patterns may change given an alternative future acid emission scenario. In the second step, the impacts of acid rain on crop yields are estimated. Finally, the yield response estimates are included in a land model to assess the impacts of acid rain on regional agricultural production and production potential in Ontario. The scenario identified in this paper assumes that future acid emissions will decrease such that rain across Ontario becomes "unpolluted" by acids. Information derived from experiments in controlled environments (greenhouses, growth chambers and laboratories) and in the field are used to estimate the yield responses of selected crops grown in Ontario if acid pollution was eliminated from rain. Changes in regional production are then calculated for each county in southern Ontario by applying the yield response estimates to current land-use patterns of agricultural production. The implications of acid rain for production potential are determined using a model which maximizes the proportion by which current production levels can be exceeded given constraints on land availability, product mix and levels of rain acidity. Results reveal that overall impacts of acid rain on agricultural production and production potential are relatively small. It is estimated that the province is incurring an annual loss of about $43 million (representing about 2 per cent) due to acid rain. Although the impacts on total production are modest, it is shown that for some crops and regions the effects are more pronounced. The study illustrates the potential of models to assess the effects of changes in environmental conditions on the use of land resources from the local to the national scale.

INTRODUCTION

Land provides the means of satisfying many societal demands. It is an essential factor in the production of food and fibre, the provision of minerals, fuels, shelter and recreation, and maintenance of productive ecosystems. Social, economic and environmental changes will have significant impacts on these various land uses. Agriculture is one important use of land which is affected by such changes. Urban expansion and other socio-economic changes, as well as environmental changes such as climate modifications, soil erosion and air pollution all have the potential to influence food production. One of the functions of land modelling is to assess the impacts of changes (whether

social, economic or environmental) on land uses such as agriculture. This paper demonstrates the application of a modelling procedure to assess the implications of environmental change for food production.

A major environmental change which has attracted much attention in recent years is acid rain. Acid rain is primarily the result of sulphur dioxide (SO_2) and nitric oxides (NO_x) being emitted into the atmosphere from anthropogenic sources. These oxides are then chemically transformed in the atmosphere by hydrolysis and oxidation to mixtures of sulphuric and nitric acids before returning to the earth in precipitation (Likens et al., 1979). In Ontario and in other industrial areas of the world the effects of prolonged acid precipitation on aquatic and forest ecosystems are well documented (Crocker and Forster, 1985; Rutherford, 1984). Considerably less attention is devoted to assessing the impacts of acid rain on agricultural production, despite evidence that acid rain may have adverse effects on the growth and yield of some crops. The analytical framework developed here is applied to assess the implications of acid rain for agricultural production in Ontario. However, while focussing on acid rain's effects on agriculture in Ontario, the framework is sufficiently adaptable that it can effectively be applied to any environmental change and regional scale.

The paper consists of two main sections. The first presents the modelling framework adopted in this study. The framework is applied to estimate acid rain's effects on agricultural production in Ontario in the second section.

MODELLING FRAMEWORK

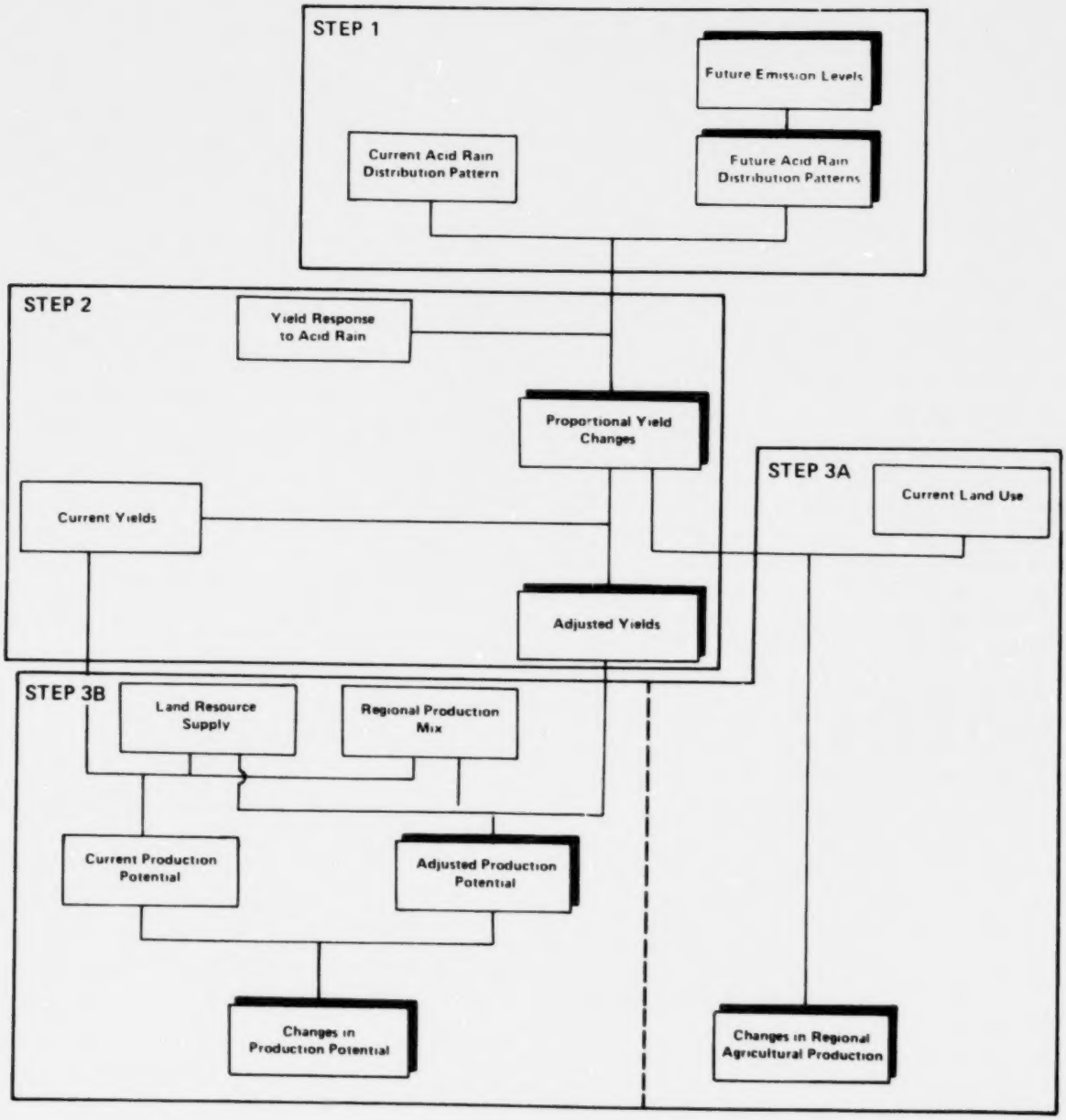
The modelling framework developed here involves the following three step procedure:

1. determining the degree to which acid rain distribution patterns may change in the future,
2. given these changes, estimating the extent to which yields are affected, and
3. applying these estimates to determine the impacts on regional agricultural production and on agricultural production potential in Ontario.

Effects on regional production are calculated by applying acid rain-induced crop yield change estimates to current land-use patterns. The county is chosen as the scale at which to assess these regional effects since data on production are available for each county and rain acidities can easily be determined at this scale. Impacts on production potential are determined using a mathematical programming model developed at the University of Guelph (Land Evaluation Group [LEG], 1983). By allowing land-use patterns to change, the model provides measures of the maximum proportion current production levels can be exceeded given specified levels of resource availability, technology and management, product mix and requirements, and yields.

The three steps in the modelling procedure are depicted in Figure 9.1. In order to determine the degree to which acid rain levels may change in the future (Step 1) the present and possible future distribution patterns of acid rain in Ontario must be identified. Currently there are a number of stations scattered across Ontario which routinely measure precipitation chemistry. By utilizing data from these stations it is possible to identify the current rain acidity distribution pattern. Predicting possible future distribution patterns, however, is difficult. Rain acidity levels are essentially dependent on future emissions of SO_2 and NO_x. Consequently, future emission levels and the relationship between emissions and rain acidities should be known prior to predicting possible future acid rain distribution patterns. In this paper, this information is used to define one possible acid rain distribution pattern or scenario for Ontario, although other scenarios may also be specified. Changes in rain acidities from current to the levels assumed in the scenario are provided

FIGURE 9.1: MODELLING FRAMEWORK



for each county and each region (i.e., climate zone) identified in the Guelph programming model.

The second step in the analysis requires that relationships between rain acidities and yields be determined. Given these relationships and the acid rain distribution patterns identified in Step 1, it is possible to estimate the proportion by which current yields may change. These proportional changes are provided for 17 crops so that changes in current crop production resulting from acid rain can be determined for each county. The estimated changes are also applied to current crop yields (as defined in the production potential model) to establish acid rain adjusted crop yields for each climate zone. These estimated yields are required in the production potential programming model.

Steps 3A and 3B use the information provided in Step 2 to assess the impacts of acid rain on regional agricultural production and production potential respectively. Assessing the impacts of acid rain for regional agricultural production involves applying data on proportional yield change to current patterns of agricultural production. To isolate the effects of acid rain on production, current agricultural land-use patterns, fertilizer use and all other inputs are held constant.

Evaluating the implications of acid rain for production potential (Step 3B) is more difficult and uses a more detailed approach. Current production potential is first calculated with respect to the current crop yields, production mix and available land resource supply using the programming model. This measure represents production potential at present acid rain levels. The programming analysis is then conducted using yield figures (for each climate zone) which have been adjusted for the alternative acid rain scenario, while all conditions including production mix and land resource supply are held constant. An adjusted measure reflecting production potential for the specified acid rain scenario is thereby provided. The change in long-term production potential resulting from a change in acid rain levels is determined by comparing the current production potential measure with this acid rain adjusted measure.

IMPLICATIONS OF ACID RAIN FOR AGRICULTURAL PRODUCTION IN ONTARIO

Acid Rain Distribution Patterns

A common measure of the acidity of a solution is pH. The pH scale ranges from 0 to 14, with a value of 7 representing a neutral solution, values below 7 indicating higher acidity and values above 7 indicating higher alkalinity. A pH of 5.6, which is the pH of distilled water in equilibrium with atmospheric carbon dioxide (CO_2), is generally accepted as a "convenient" reference value for "unpolluted" or "pure" precipitation (Likens et al., 1979). Precipitation with pH values below 5.6 is then considered to be abnormally acidic and termed "acid precipitation".

Limited data suggest that precipitation falling in eastern North America prior to the Industrial Revolution generally had pH values greater than 5.0 (Likens et al., 1979). As sulphur and nitrogen emissions from anthropogenic sources increased so did precipitation acidities (Memorandum of Intent [MOI] Work Group, 1983). By the 1950s evidence revealed that precipitation may have already become highly acidic (pH less than 5.6) (Junge and Gustafson, 1956), and it is believed by some that this acidity has been spreading and intensifying over eastern North America since (Cogbill, 1976; Likens et al., 1979). Today, average annual precipitation pH ranges from about 4.5 to 4.0 across Ontario (Ontario Ministry of the Environment [OME], 1983), which is 10 to 50 times more acidic than the lowest value expected for an unpolluted atmosphere (pH 5.6). These pH values tend to be even lower in the summer months. This is believed to be a function of the air masses which dominate the weather in Ontario (Summers and Whelpdale, 1976). In the summer months prevailing winds are

from the south and carry pollutants from industrial areas in the United States, while in the winter months unpolluted Arctic air makes frequent incursions into Ontario.

The acid rain distribution pattern for the current growing season has been identified (Figure 9.2) utilizing average 1981 monthly rainfall pH values collected from sampling stations in Ontario (OME, 1983). Figure 9.2 indicates that, generally speaking, the highest rain acidities occur in the southwest and southeast portion of Ontario, while central and northern Ontario experience lower rain acidities. Rain acidity also decreases toward the north. This distribution pattern is a reflection of both the industrial activity in Ontario and the prevailing wind patterns. Average pHs for each county in southern Ontario and the land regions specified in the production potential model (i.e., areas with similar climates and soil conditions) were determined from Figure 9.2 in order to perform the analyses.

Estimating future rain pH levels in Ontario is subject to several major difficulties. The acidity of rain is fundamentally related to SO_2 and NO_x emission levels. Projections for future emissions are difficult to make because they depend on government pollution control policies, economic conditions, and future energy supply options, factors that cannot be forecast accurately. In addition, the relationships between emission levels and acid rain distribution patterns are difficult to ascertain since they are the outcome of the location and concentration of emissions and the prevailing wind patterns, air temperatures, barometric pressures and background pollution levels. This paper assumes one hypothetical rain pH pattern or scenario although other scenarios may be specified and easily accommodated in this modelling framework.

The scenario specified in this paper assumes SO_2 and NO_x emissions will decrease substantially as a consequence of pollution control policies instituted in the United States and Canada. Accordingly, all counties and land regions (as specified in the production potential model) are presumed to have growing season average rain pHs of 5.6. A pH of 5.6 implies that rain is no longer "acid polluted". This scenario, therefore, provides an assessment of the implications for agricultural production if rain was unpolluted by acids.

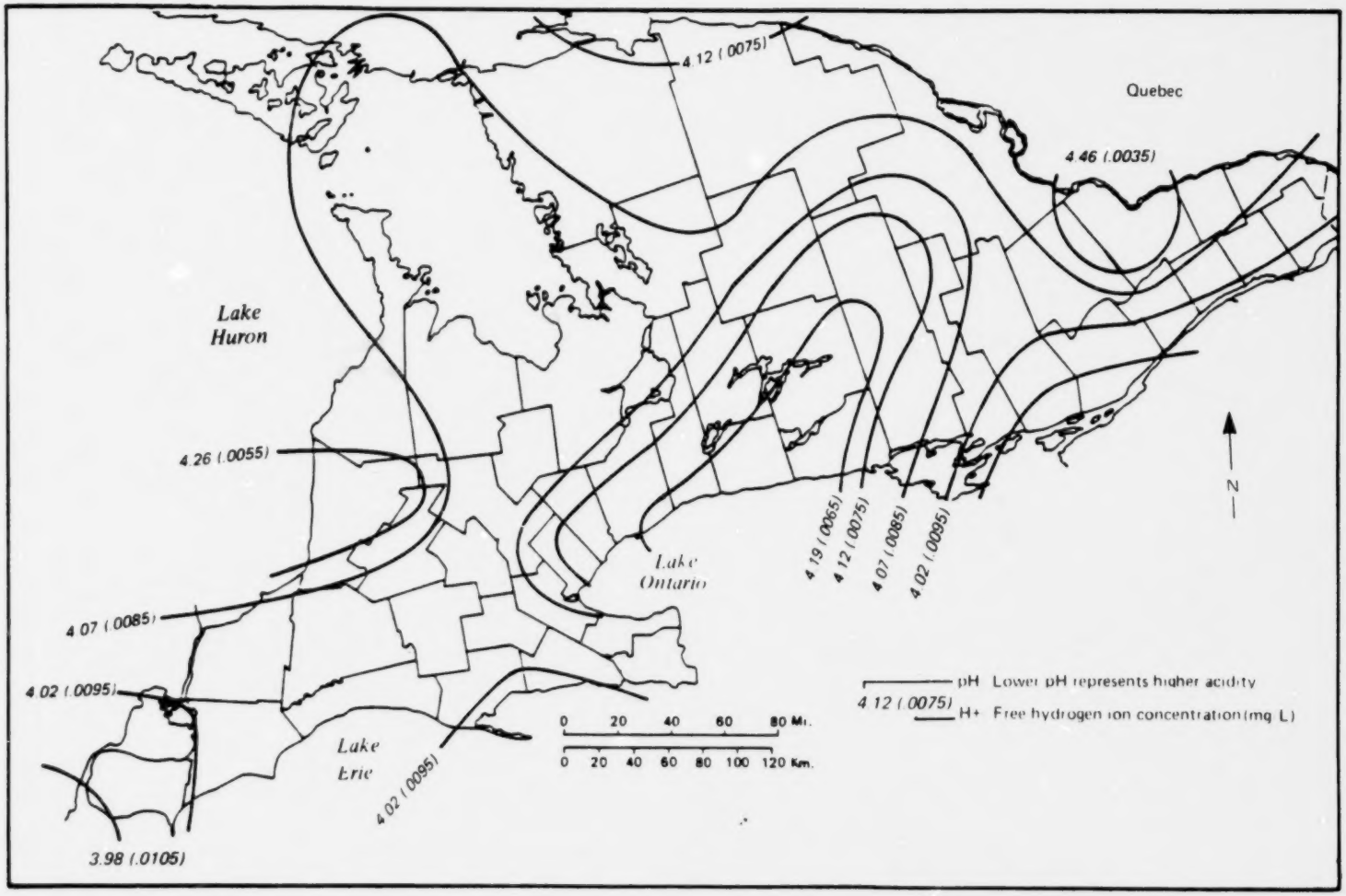
The Effects of Acid Rain on Selected Crop Yields

Acid rain affects crop yields in two ways, indirectly by acidification and demineralization of soils, and directly by contacting foliar surfaces (Coote et al., 1981). In Ontario, it is unlikely that crops will be affected by acid rain via the soils for some time, since most agricultural soils in the province are calcareous and capable of neutralizing acids. Moreover, the addition of acids to soils by rain is negligible compared to that added through fertilization (Irving, 1983). For these reasons, concern is primarily with the direct effects acid rain has on crop yields; that is, the effects of acid rain falling upon crop foliage.

Information on the direct effects of acid rain on crop yields is developed through experiments in controlled environments (greenhouses, growth chambers and laboratories) and in the field (Irving, 1983). These experiments involve exposing crops to simulated rain treatments of different pH levels, under monitored conditions, and determining crop yield response. Crop yield response is a measure of the proportional change in the marketable portion of the crop which results under changing rain pH treatment levels. By interpolating between these rain pH levels, it is possible to estimate yield responses over a range of pH levels. By reviewing a wide range of experiments, the yield responses of 17 selected field, fruit, and vegetable crops if rain was unpolluted by acids were identified.

Since many experiments have been performed, differing in design and approach, criteria for selecting those which provide the most likely

FIGURE 9.2: ACID RAIN IN SOUTHERN ONTARIO



crop yield responses have been suggested. When crop response data derived from field experiments were available, these were chosen in favour of those derived from controlled environmental experiments, because field studies are considered to be a more realistic means of estimating actual effects (Irving, 1983). Similarly, experiments using simulated sulphuric-nitric acid rain were assumed to be more representative of ambient acid rainfall than those using only simulated sulphuric acid rain. Crops for which there have been no reported experiments were assumed to respond to acid rain in the same manner as related crops for which data were available.

The experimental data on crop responses indicate that as simulated rain pH changes to 5.6 from the current level, yields of the selected crops react in one of three ways. Some crops exhibit increases in yields, others decreases, while others show no change whatsoever (Table 9.1). Experiments show that the yields of crops such as corn, soybeans and some fruits will increase if rain was unpolluted by acids (Evans et al., 1984; Forsline et al., 1983a and 1983b; Lee and Neely, 1980). This means that at present rain pH levels these crops are adversely affected. These adverse yield effects are attributed to the fact that acid rain interferes with the development and survival of the crop's reproductive systems (Evans, 1982). On the other hand, some crops including hay and tobacco actually show yield decreases in the experimental situation when rain acidities are decreased (Lee et al., 1981). In other words these crops benefit from acid rain, at least at present rain acidity levels. Since limited amounts of sulphur and nitrogen are essential to plant nutrition, it is reasoned that moderately acidic rain acts as a fertilizer and stimulates the growth and yield of certain crops (Irving, 1983). As the acidity of the rainfall increases beyond the current rain acidity levels in Ontario (approximately pH 4.0), experiments show that the yields of most crops begin to decrease (Lee et al., 1981). Finally, many researchers report that wheat, oats, and barley are resistant to acid rain and exhibit no change in yield weights as rain pH changes to 5.6 (Evans et al., 1982; Lee et al., 1981).

TABLE 9.1: CROP YIELD RESPONSES TO THE REMOVAL OF ACID RAIN

YIELD RESPONSE	CROPS
No Change	Barley
	Oats
	Mixed Grain
	Winter Wheat
Increase	Apples
	Fodder Corn
	Grain Corn
	Grapes
	Peaches
	Potatoes
	Soybeans
	Sweet Corn
Decrease	Field Beans
	Green Peas
	Hay
	Tobacco
	Tomatoes

The experimental results were utilized to develop estimates of the proportions by which yields of the selected crops would change if rain was unpolluted by acids. These proportional estimates are presented elsewhere (Ludlow, 1986), and form the basis for assessing both the impacts on regional agricultural production and on production potential if rain was unpolluted by acids.

Acid Rain's Impacts on Agriculture

Assuming land-use patterns, inputs, etc. remained fixed, estimated yield responses were used to determine the effects on regional production in the following manner. First, the yield response estimates obtained from the review of the field and laboratory experiments were applied to present levels of

production (tonnes) and farm value of production (1981 dollars) for each crop in each county to obtain measures of production changes attributable to acid rain (Ludlow, 1986). Second, the changes in farm value of production measures were summed over all selected crops and expressed as a proportion of total farm value of production of all selected crops combined in each county. These proportional change values were then used to illustrate the regional impacts on total production if rain was unpolluted by acids (Figure 9.3). The magnitude and direction of the proportional change is dependent upon the mix of crops grown in the county and their various responses to the specified acid rain levels. To facilitate comparisons between the pattern of proportional changes and the pattern of current total farm value of production, the current (1981) total farm value estimates of all 17 crops combined were also mapped.

Figure 9.3 shows that if rain was unpolluted by acids most counties would exhibit increases in total farm value of production. The greatest increases would generally occur in counties located in the south and southwest portion of the province, which is also the region with the greatest production value. A notable exception, however, is Haldimand-Norfolk County, (located on the north shore of Lake Erie), which displays a relatively large decrease in total farm value of production (Figure 9.3). This decrease is a reflection of the fact that Haldimand-Norfolk is the largest tobacco producing county in Ontario, and tobacco yields would decrease if acid rain was eliminated (Table 9.1). Tobacco also has the highest farm value per unit weight of all selected crops (Ontario Ministry of Agriculture and Food [OMAF], 1982). A number of counties located in northern Ontario would also exhibit decreases in total farm value of production, but these are negligible compared to that estimated for Haldimand-Norfolk. Reciprocally, these results indicate that counties in the south and southwest are incurring losses in total farm value of production at current levels of acid rain. In other words, in terms of current value of production these counties are the most sensitive to acid rain. Again, the Haldimand-Norfolk County is an exception; the current total farm value of production in Haldimand-Norfolk is actually higher than would be expected if there was no acid rain.

Measures of the aggregate effects on total provincial production and production potential are also presented (Table 9.2).

By summing over all crops and all counties the changes in value of farm production attributable to acid rain, the total provincial farm value of production would increase above the 1981 level (of $2,153 million) by approximately $43 million, and become $2,196 million (Table 9.2). This result may also be interpreted another way: at current rain pH levels the province is incurring a loss in total farm value of production of $43 million annually. Although a change of $43 million is consequential, it represents only about a 2 per cent change in total farm value of production.

The effects of acid rain on production potential are similar to the findings on the impacts of acid rain on total provincial farm value of production. When the programming analysis was conducted using information on current crop yields, product mix and resource supply, the production potential was calculated as 1.30 (Table 9.2). This means that the resource base has a capacity to increase the production of all crops by at least 30 per cent over current levels. If rain was unpolluted by acids the excess capacity would be 33 per cent. Production potential under these conditions is 1.33 (Table 9.2). This increase, as is the case with the expected increase in total provincial farm value of production, represents only a modest improvement (about 2 per cent) over the current conditions. Given that production of all selected crops grown in Ontario can currently be increased by about 30 per cent, cleaning-up acid rain would not have a major impact on agricultural production potential. Acid rain alone is not likely to threaten future food producing capabilities of the province.

FIGURE 9.3: IMPACTS OF ACID RAIN ON REGIONAL PRODUCTION

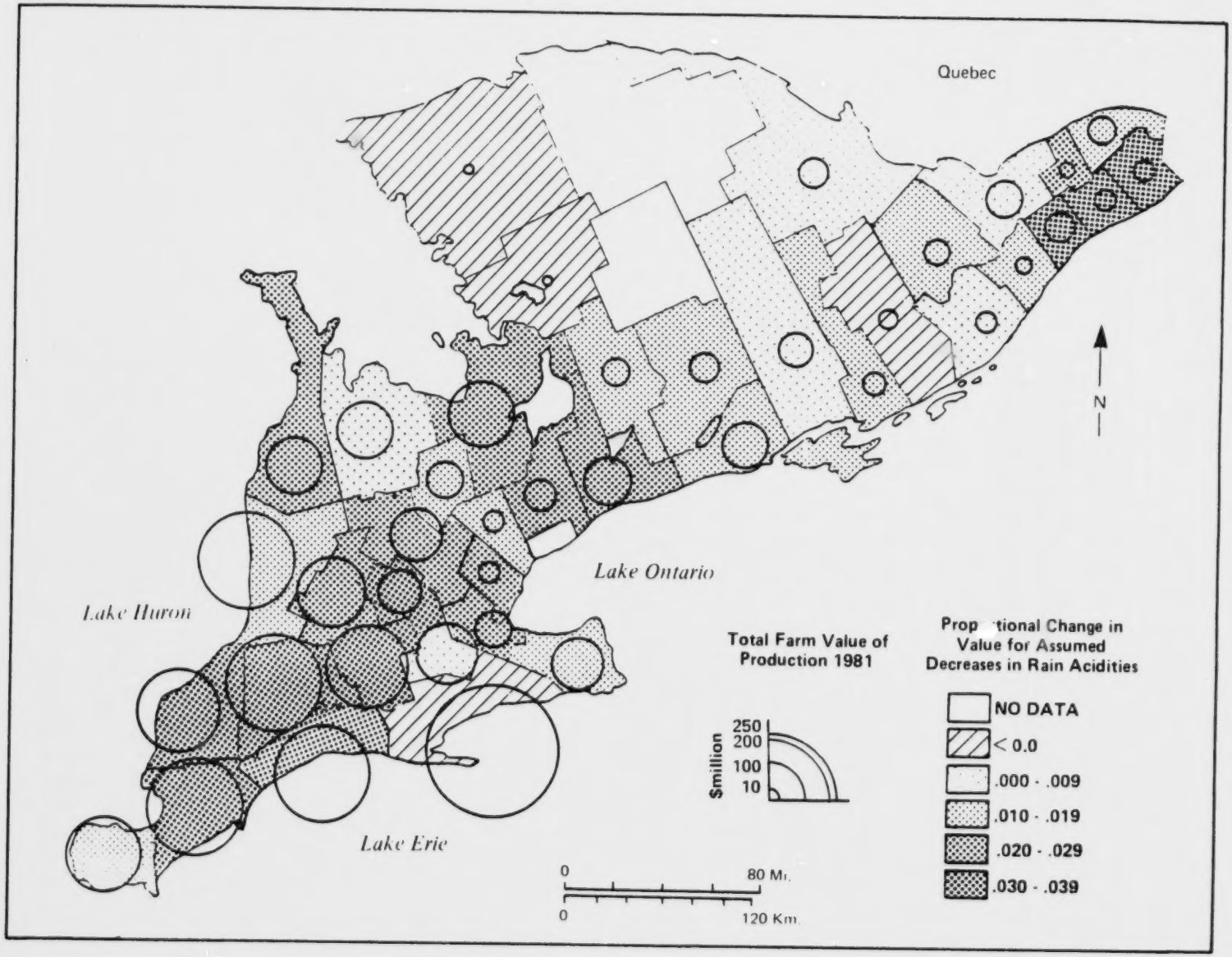


TABLE 9.2: CHANGES IN TOTAL PRODUCTION AND PRODUCTION POTENTIAL IF RAIN WAS UNPOLLUTED BY ACIDS

TOTAL VALUE OF PRODUCTION	
1981 Conditions	$2,153 million
Clean Acid Rain Scenario	$2,196 million
Per Cent Change	2.0
PRODUCTION POTENTIAL	
1981 Conditions	1.30
Clean Acid Rain Scenario	1.33
Per Cent Change	2.3

CONCLUSIONS

The major purpose of this paper was to develop a modelling framework to assess the implications of environmental change for agriculture. The framework was applied to assess the effects on regional agricultural production and production potential in Ontario if rain was unpolluted by acids. Under these conditions it was found that total impacts on production and production potential were modest. Both total farm value of production and production potential of the resource base will increase by only about 2 per cent if acid rain was eliminated. Although this is proportionally small, it represents a $43 million increase in total farm value of production annually. Furthermore, implications for particular regions and crops are more pronounced.

This exercise demonstrated that it is possible to assess the implications of environmental change on land-use activities such as agriculture in a systematic manner. The framework developed is sufficiently adaptable that it may effectively be applied to other environmental and socio-economic changes affecting agriculture, including urban expansion, soil erosion and climatic change. It may also be applied at any broad regional scale. Finally, any number of environmental change scenarios may be specified in the framework. In this example, scenarios representing future increases in acid rain levels can be identified and assessed.

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10

EVALUATION OF THE IMPACT OF ACID DEPOSITION ON EASTERN CANADA'S SPORT FISHERY

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ABSTRACT

Under the Long Range Transportation of Atmospheric Pollutants (LRTAP) program, the Department of Fisheries and Oceans (DFO) required an estimate of the economic impact of acid deposition on eastern Canada's sport fish industry. The project required a biophysical model to predict the impact of alternative deposition scenarios on sport fish catch rates. The results of the biophysical model were used to drive the economic model. This project is the first successful integration of a biophysical and economic model under the LRTAP program.

The paper deals with the biophysical model through the biophysical concepts employed, the modelling approach used and the use of a microcomputer based geographic information system (SPANS) to run the model and display the results. The results, presented in map form, indicate increases in catch of greater than 6 per cent for large tracts of north-western Ontario and along the north shore of the St. Lawrence.

INTRODUCTION

This paper deals with the biophysical modelling approach taken by the DPA Group to provide the Department of Fisheries and Oceans (DFO) with an economic evaluation of the impact of varying acid deposition scenarios on eastern Canada's sport fishery. The biophysical model identifies the per cent change in fish availability to anglers under various deposition scenarios, for input to an economic model. The first section of this paper identifies some of the biophysical concepts involved in the impact of acid deposition on sport fish. The second section outlines the methodology used in the spatial analysis.

BIOPHYSICAL CONCEPTS

The following section briefly outlines some of the important factors related to changes in water chemistry and effects on fish due to acidic deposition.

Watershed Acidification

The initial step in the impact of acidification on sport fish is the emission, transportation and deposition of sulphates. The acidic depositions lower the pH of poorly buffered surface water systems. As pH is reduced, impacts on fish species increase until loss of populations begins to occur. It is necessary to identify the linkages between deposition, the impact on surface water chemistry, fish damage, and resulting changes in fish populations, in order to model the impacts of various deposition scenarios on fish availability.

The DFO and the Environmental and Social Systems Analysis Ltd. (ESSA) have developed a large-scale regional model for the prediction of acidification of waters in eastern Canada. The model incorporates parameter distributions by secondary watersheds from comprehensive federal and provincial databases for specific water quality parameters and watershed characteristics. The model is based on the steady state assumption that water bodies reach an eventual equilibrium with respect to acidic deposition. Mass balance calculations are utilized in the model to compare the steady states of lakes under different deposition scenarios. The model explicitly assumes an instantaneous response to changing acidic deposition.

Data developed for the ESSA model have been used in this study in an approach, suggested to us by Dr. C.K. Minns (1986), which depends on a calculation of the original alkalinity (or watershed attenuation capacity) available in each watershed. Alkalinity is a measure of the watershed buffering capacity and an indicator of the sensitivity of the surface waters to acidification. This original alkalinity is expressed as a distribution around the mean pH value, for lakes in the watershed. Sulphate deposition is simply subtracted from these values to indicate the increase in acidity which represents a decrease in pH.

Effects of pH on Fisheries and Damage Estimates

The effects of acidification on fish in Canadian waters have been the subject of intense investigation since the mid-1970s, but in spite of this research effort, little is known about the regional extent and rate of change of fishery resources in response to acidification (Gardner Pinfold Consulting Economists Ltd., 1984; Jones et al., 1984; Ontario Ministry of the Environment [OME], 1984; Watt et al., 1983).

Experience from Norway, the eastern United States and Canada, as well as from the experimental acidification of whole waterbodies, provides unequivocal evidence that acidic deposition results in the loss of fish populations. Numerous effects of acidic deposition on fish have been positively correlated with pH decreases prior to the loss of populations. These effects include changes in population age structure, reduced egg development, inhibition of spawning, and reduced viability of sperm and eggs.

There also appear to be species-specific and age-specific differences in the sensitivity of fish populations to acidification effects, and various authors have reported different pH ranges at which fish are first affected and eventually lost, depending on the species and system examined (OME, 1984; Watt et al., 1983). The approach used in this study for the prediction of damage functions for sport fish is based on the estimation of change in surface water pH for specified deposition scenarios and known effects of pH levels on different life history stages of important sport fish.

Sufficient information to generate damage functions for all sport fish is not available. Consequently, we have focussed on the most preferred sport fish identified in the 1980 Ontario sport fish survey; trout, walleye, bass and pike, as well as Atlantic salmon. The preferred species vary among provinces; in the Atlantic provinces the overwhelming preference is for brook trout, as many of the Ontario species do not occur.

Review of the available data suggests that three functions encompass the important sport fish; these preliminary damage functions are listed in Table 10.1. This approach improves on preceding estimates of fisheries damage by incorporating:

1. separate functions for important sport fish, and
2. providing a continuous damage function from 100 per cent to 0 per cent survival rather than an estimate of the threshold level at which there is 100 per cent loss of fish.

TABLE 10.1: PRELIMINARY DAMAGE FUNCTIONS FOR SPORT FISH IN EASTERN CANADA

FISH	pH FOR 100 PER CENT POPULATION SURVIVAL	pH FOR 50 PER CENT POPULATION SURVIVAL	pH FOR 0 PER CENT POPULATION SURVIVAL
Group 1 Lake trout Rainbow trout	6.0	5.5	5.0
Group 2 Atlantic salmon Large mouth bass Walleye Brook trout	5.5	5.1	4.6
Group 3 Northern pike Small mouth bass	5.0	4.7	4.3

ESTIMATING THE CHANGE IN SPORT FISH AVAILABILITY

Figure 10.1 illustrates the methodology used to estimate changes in the availability of sport fish. This section describes some of the characteristics of the data sets and assumptions used in the modelling. The model links deposition to changes in lake pH and to fish damage. The model also considers the distribution of sport fish species and the relative proportion of species within a region. The model is run on the TYDAC Inc. Spatial Analysis System (SPANS) which is a microcomputer-based geographic information system (GIS). The SPANS is used to input the spatial data, to manipulate the equations and to output the intermediate and final maps, as well as area analysis reports.

Fish Distribution and Production

In order to determine the change in fish availability within a region it is necessary to map the distribution of the sport fish. There are few sources of fish distribution data, and few surveys have been conducted to delimit distributions. We used distribution maps from Scott and Crossman (1974).

There has been no application, on a uniform basis, of fish population estimates for eastern Canada, nor of the productivity of fish habitat. In the absence of good biological data, the only alternative was to use catch statistics as a relative weighting of fish species abundance. These catch statistics are used in conjunction with fish distribution maps.

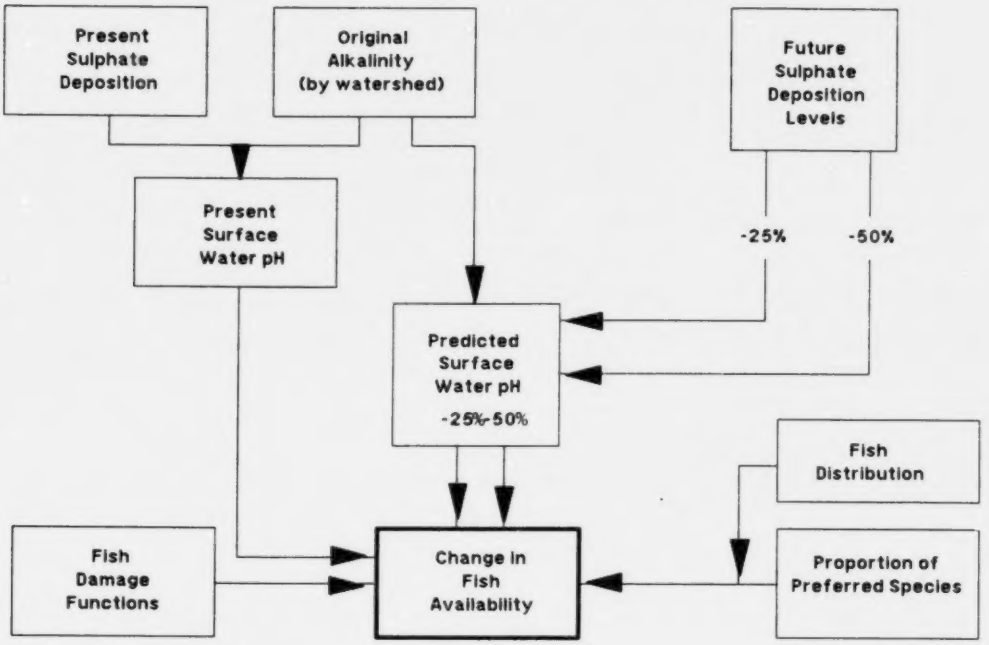
Acidic Depositions

Deposition levels are an assumed input. We have evaluated the effects of the following scenarios:

1. 1980 deposition reduced by 25 per cent, and
2. 1980 deposition reduced by 50 per cent.

These values were suggested by Environment Canada.

FIGURE 10.1: PROCEDURE FOR ESTIMATING EFFECTS OF ACIDIFICATION ON SPORT FISH USING ORIGINAL ALKALINITY



The approach simply decreases sulphate values for each watershed by 25 per cent and 50 per cent respectively and recalculates the proportion of lakes at various pH levels (based on the subtraction of sulphates from the original alkalinity values provided from the DFO/ESSA model). This results in pH data on a watershed basis for 1980 (the base year), 25 per cent reduction, and 50 per cent reduction in acid deposition.

Different acidic deposition scenarios could be tested using this method.

Fish Damage Functions

The concept of thresholds has been widely used in estimating damage functions. This is, of course, a simplification of the actual response. The response does appear to be a very steep curve, and we have therefore adopted a modified threshold approach as shown in Table 10.2.

Straight lines are assumed to connect the three fixed points for each fish group (0 per cent, 50 per cent and 100 per cent). These lines divide the distribution of lakes into three classes; those with complete, partial and no survival. By integration, the area (representing the survival of fish) below the line can be calculated. In effect, this defines a continuous damage function as opposed to a threshold effect.

Figure 10.2 illustrates how this calculation is performed. The horizontal axis represents alkalinity, acidity and sulphate all expressed in micro equivalents per litre. The distribution of present pH for lakes in each secondary watershed was plotted from the average value and standard distribution for each watershed, derived from the ESSA model. This curve shifts to the right as the amount

FIGURE 10.2: DISTRIBUTION OF pH IN LAKES IN A SECONDARY WATERSHED, CALCULATED FROM ORIGINAL ALKALINITY, WITH PRESENT AND HYPOTHETICALLY REDUCED SULPHATED DEPOSITION LEVELS, PLOTTED AGAINST FISH MORTALITY

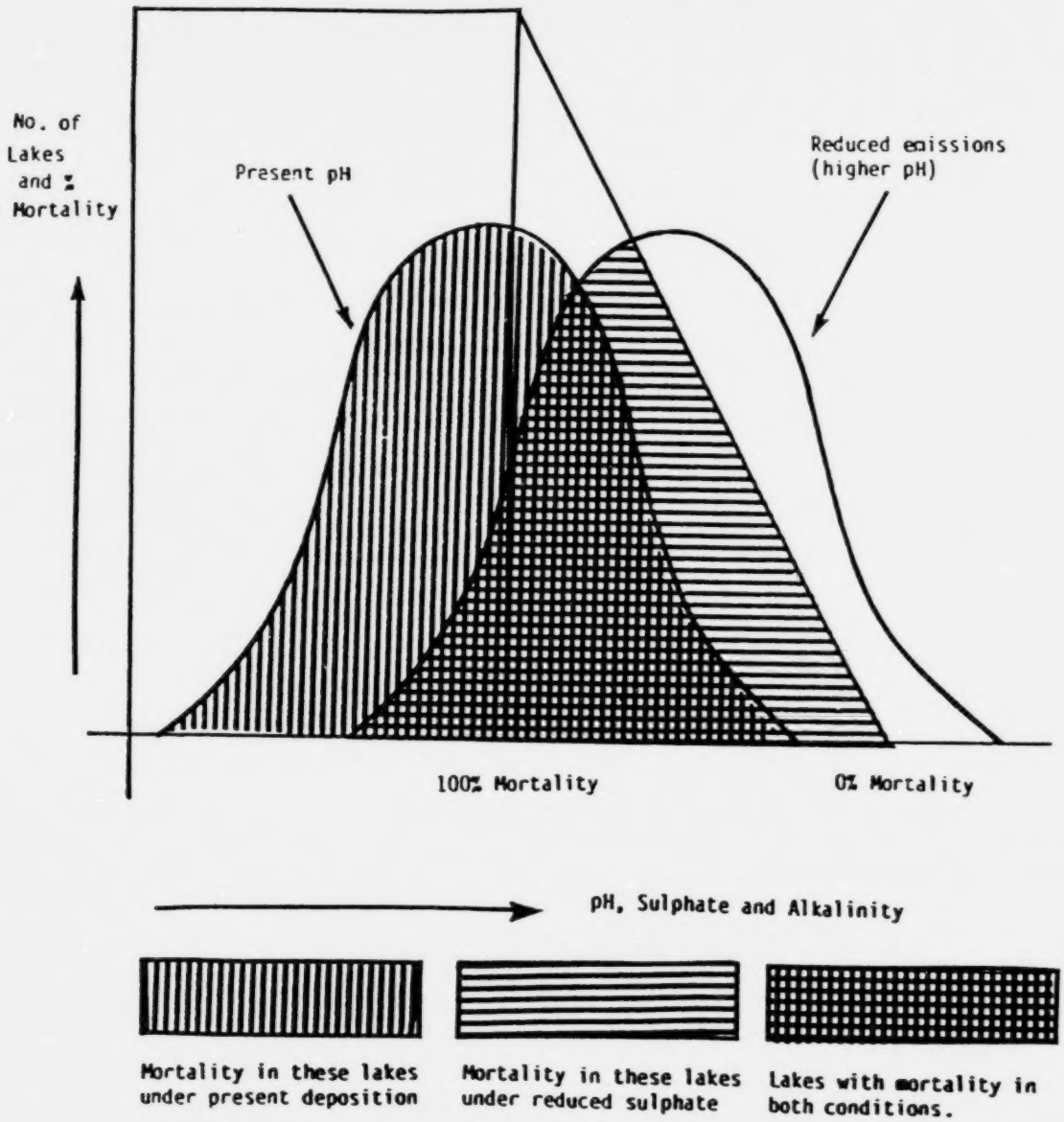


TABLE 10.2: CRITICAL pH LEVELS IN SURFACE WATERS FOR SPORT FISH

pH	RESPONSE
6.0	Group 1 affected
5.5	Group 1 survival less than 50 per cent Group 2 affected
5.1	Group 2 survival less than 50 per cent
5.0	Group 1 eliminated Group 3 affected
4.7	Group 3 survival less than 50 per cent
4.6	Group 2 eliminated
4.3	Group 3 eliminated

of sulphate deposited is decreased (25 per cent and 50 per cent). A present measure of sulphate deposition for each watershed was derived from the Canadian Network for Sampling Acid Precipitation (CANSAP) maps using the SPANS to perform area calculations.

Fish damage functions for each fish group are plotted on this same graph. In effect the area of the distribution curve falling under the damage function is a measure of the actual mortality of each fish group. This area is reduced as the pH is increased by progressive reductions in sulphate depositions. The further right the distribution curve is shifted the lower the mortality. This calculation is performed for each fish group in each secondary watershed.

The per cent change in survivability is simply determined by subtracting the 1980 survival rates from the survival rates estimated for the 25 per cent and 50 per cent reduction scenarios. The total change in fish availability is determined from the weighted average change in individual fish species, by summing the increase in each fish species survival by the fish species density, for each watershed. Density is determined from overlaying the fish distribution maps with the catch statistics map, where:

$$\text{Density} = \frac{\text{Number of Fish Species A, caught in the Catch Area B}}{\text{Area of Fish Species A Distribution, in Catch Area B.}}$$

The final manipulation pro-rates the watershed change in availability to the economic region level. It is this change in fish availability by economic region data that is input into the economic model.

Figures 10.3 to 10.8 illustrate the steps taken in the biophysical analysis. Figure 10.3 indicates the sulphate deposition pattern for the baseline year 1980. In Figure 10.4 the mean pH values for the lakes in each watershed, for which data are available, are displayed in ranges. (In the analysis actual values were used rather than ranges). Figure 10.5 demonstrates one of the eight fish distribution maps used in the analysis, whereas Figure 10.6 provides the spatial framework for the catch statistics. The average pH change for each secondary watershed is presented in Figure 10.7. Results are shown for each of the two scenarios; 25 per cent and 50 per cent reduction in sulphate deposition. For each of the changes in pH reported in Figure 10.7, a corresponding increase in fish survival is calculated (Figure 10.8). This uses the approach described in Figure 10.2.

RESULTS

The results of the analysis, which form the input for the economic model, are expressed as change in fish catch (from 1980), using the fish damage functions, fish catch and

FIGURE 10.3: SO_4 DEPOSITION, 1980

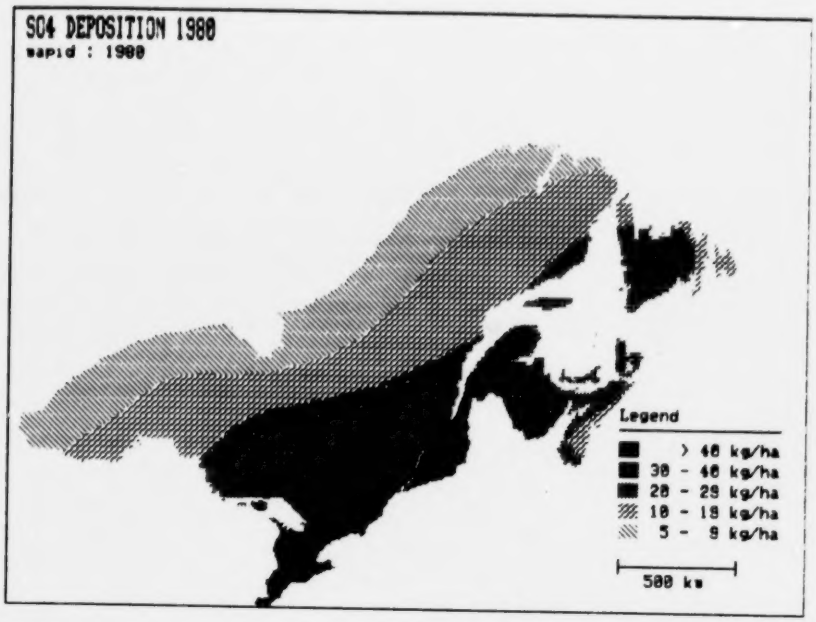


FIGURE 10.4: PRESENT pH, 1980

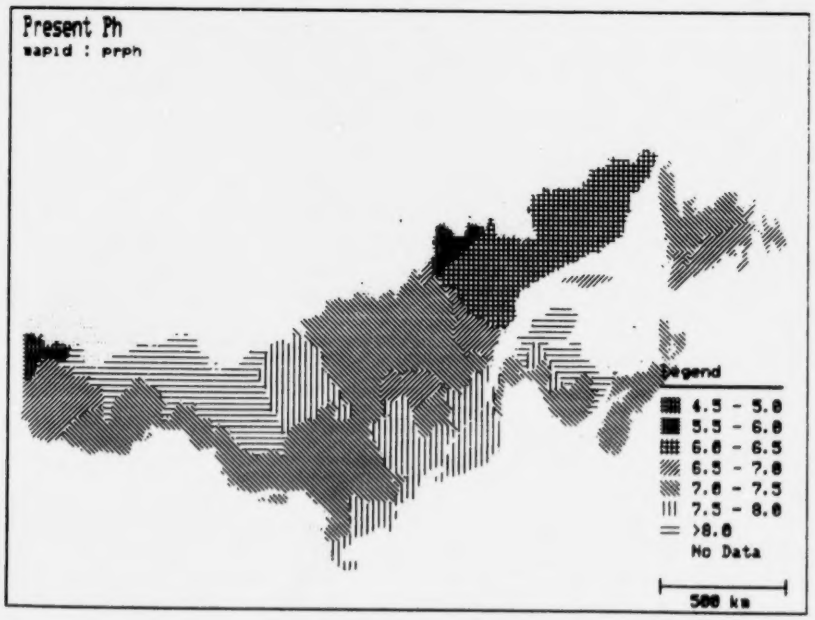


FIGURE 10.5: FISH DISTRIBUTION

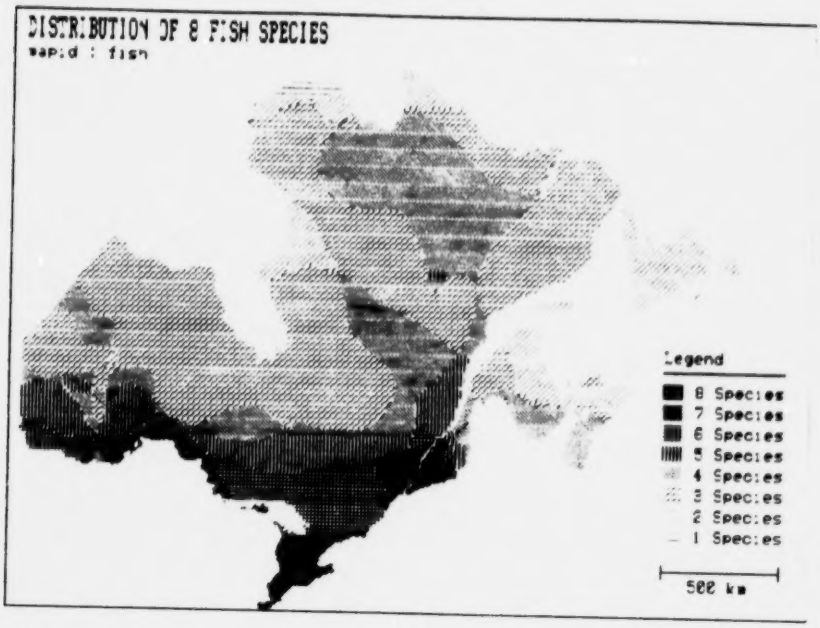


FIGURE 10.6: CATCH AREAS

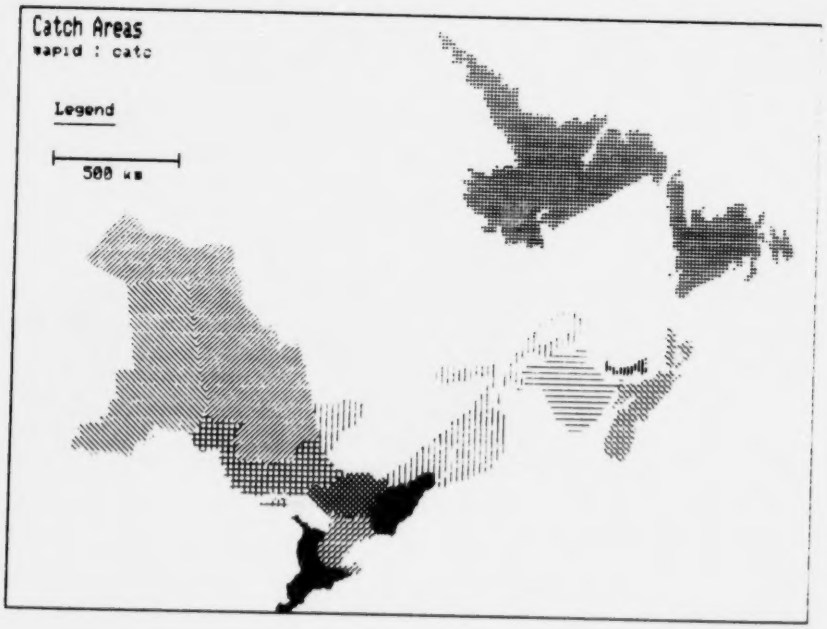
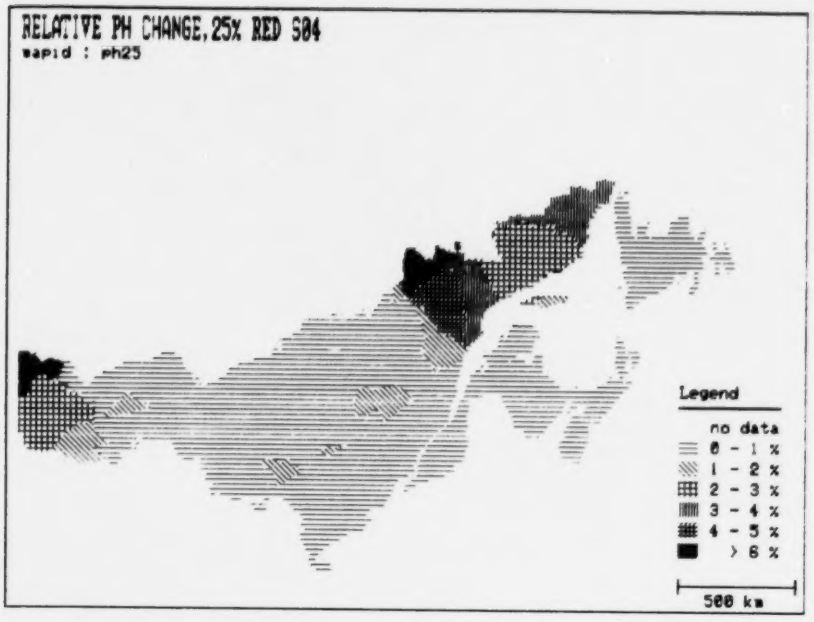


FIGURE 10.7: RELATIVE pH CHANGE



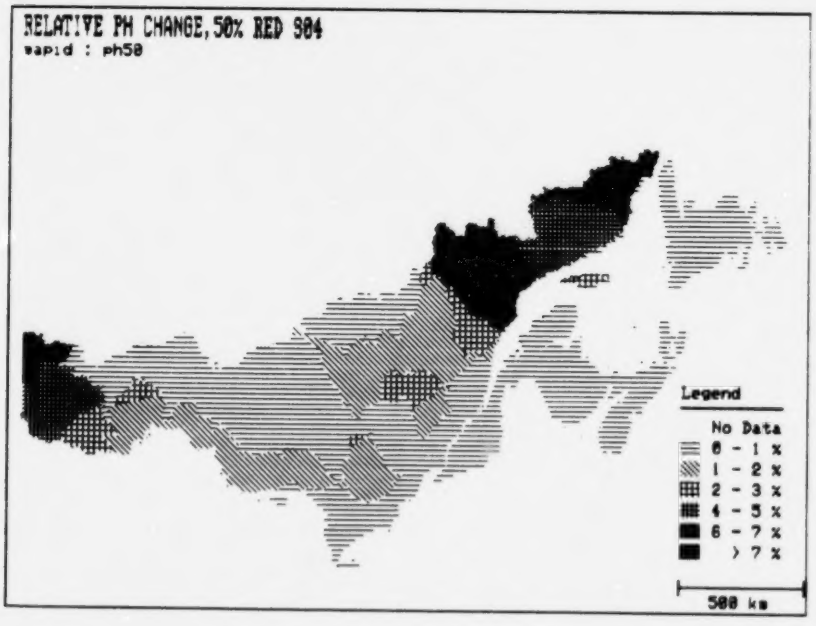
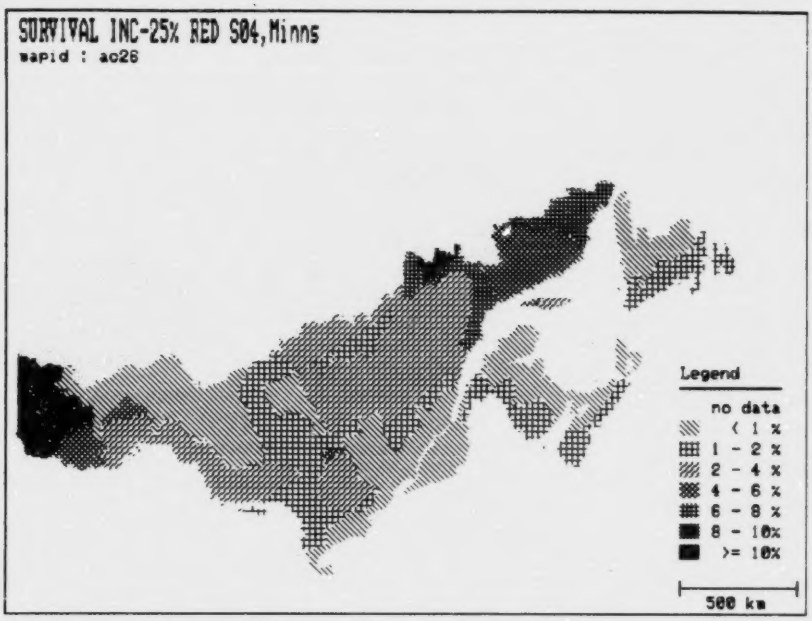
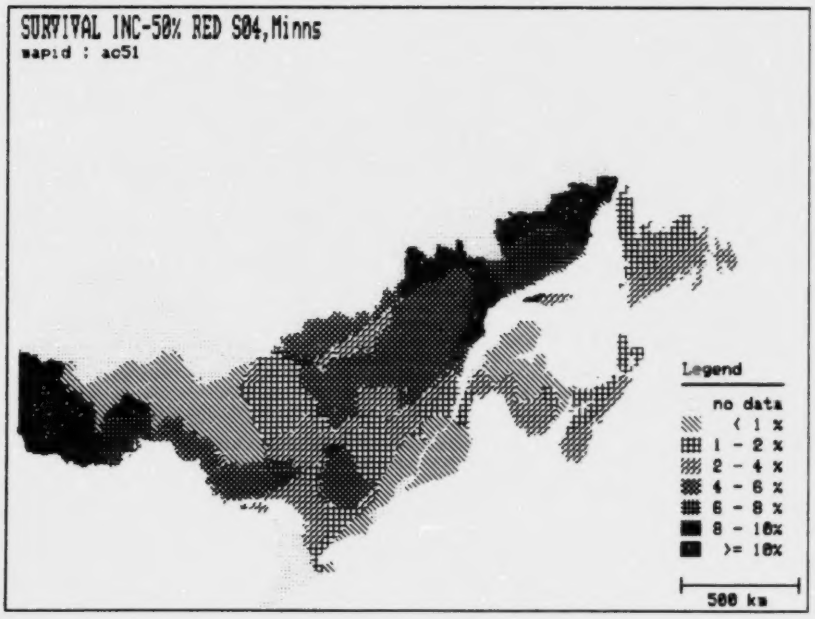


FIGURE 10.8: SURVIVAL INCREASE





predicted surface water pH.

Interpretation of Results

At first glance, the results probably seem very small; much less than might be expected. This is because the distribution of highly acidified water is a response to the watershed attenuation capacity and not primarily a response to sulphate deposition.

The weighted average by fish species plays an important role in the results. For instance many may think of Atlantic salmon as the dominant sport fish in the Atlantic provinces however, brook trout account for more than 87 per cent of the weighted percentage change in all four of the Atlantic provinces. Brook trout are in Group 2, which is affected below pH 5.5 and is absent below pH 4.6. In the low original alkalinity watersheds of southern Newfoundland and Nova Scotia, reduction by 50 per cent of the comparatively low deposition of sulphates produces an increase in fish availability of only 2 to 3 per cent.

In Quebec, Atlantic salmon is the dominant preferred species, while in Ontario there is no dominant species. However in both provinces the most preferred species are all in Groups 2 and 3. The influence of salmon in Quebec is seen in the results for the north shore where the highest increases in preferred species survival (about 10 per cent) are reported.

Even in very poorly buffered watersheds, most surface water is above the critical pH levels for Group 2 fish. In other words, the effect of reducing deposition of sulphate is not dramatic because very few of the watersheds have been affected by current acidic deposition sufficient to significantly damage the preferred species.

Modelling Approach and Revision

The modelling approach relied heavily on the use of the SPANS to perform the modelling and area analysis. The SPANS was employed to overlay the sulphate deposition, secondary watershed, catch area and eight fish distribution maps. The overlays resulted in 542 unique conditions. The modelling to determine the change in watershed pH, per cent change in fish availability, fish density and weighted average, required the attribute data of the 542 unique conditions.

This model is currently being revised for the DFO to account for improved fish damage function data and watershed pH data. The revised version also provides both an historical and forecast impact perspective.

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PART 4
MODELLING THE EFFECTS OF CLIMATIC CHANGE ON THE LAND RESOURCE BASE

11

THE CLIMATE ISSUE: IMPLICATIONS FOR MODELLING AND MANAGING TERRESTRIAL RESOURCES

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ABSTRACT

The value of modelling in climate impact assessment is reviewed. Attempts to link climate to resource flows (e.g., crop yields), land cover and use (e.g., vegetation), and broader economic systems are briefly described. These models can be used to project future impacts. Even in the face of great uncertainty, model scenarios can help impact assessors and policy makers explore options to improve human response to climate change.

INTRODUCTION

Climate is a conceptual construct that expresses the long-term or expected state of the atmosphere in space and time. It is generally defined by the ensemble of statistics (e.g., mean, variance, etc.) describing a standard set of atmospheric variables. In theory, climate variables include temperature, precipitation, radiation (incident and reflected), soil moisture, evaporation, atmospheric chemistry, and the nature and timing of discreet events (e.g., frosts, freeze-thaw cycles and floods). In practice, climate is described almost universally by temperature and precipitation -- terms that represent the major mass and energy flows in the climate system.

Until recently, climate research was subordinated to studies of the weather and its prediction. However, growing concern over climate fluctuations in the early 1970s, highlighted by the Sahelian drought in Africa (Hare and Sewell, 1986), and bad crop harvests in several countries during 1972 with subsequent dramatic increase in world food prices, led to international and national efforts to put climate on the research and political agenda. Among the results of this heightened concern was the convening of a World Climate Conference in 1979, and establishment of a World Climate Program including physical research, data, applications, and impacts components. Several countries, including Canada and the United States, established national climate programs.

The broad goal of the impacts components of these programs is not only to measure the actual impacts of climate on human activities like natural resources management, but to assess social vulnerability to future climate fluctuation, perhaps resulting from anthropogenic changes in atmospheric constituents (e.g., the "Greenhouse Effect" arising from increased carbon dioxide and other trace gases). Both of these goals require a better understanding of the linkages between climate and human activities.

CLIMATE AND HUMAN ACTIVITIES

Experience suggests that climate is an important, occasionally decisive, factor in

many natural resource systems. However, in planning resource management protocols, climate has been either neglected or, perhaps worse, assumed to be a stable element best described by its statistical properties during the past 30 years or so. Thus, water supply systems are designed to cope with observed climate (as translated into runoff) plus some socially-acceptable safety buffer (often defined as the capacity to deliver a minimum amount of water were the worst drought on record to recur). Rarely, however, is the potential for fundamental climate change considered even in long-term resources planning.

At their 1978 meeting in Toronto, the Scientific Committee on Problems of the Environment (SCOPE) (a standing committee of the International Council of Scientific Unions; SCOPE, 1978) set out a theoretical structure for analysing climate impacts on society. They recognized the interactive rather than passive role of society in perceiving and responding to climate fluctuation, arguing that the sensitivity and response of our resource management systems must be accounted for in any assessment of climate impacts. This simple precept, however, is not easily incorporated into climate impact models, which tend to be based on unidirectional causal chains.

MODELLING CLIMATE-RESOURCE CONNECTIONS

Qualitative and quantitative models of some climate-resource links, such as in agriculture and water resources, are well developed. However, in several systems for which our experience and intuition suggest marked climate sensitivities -- such as grazinglands, fisheries, forests, and wildlife -- the climate signal has not been readily isolated because of lack of quality, long-term data (e.g., grassland production or fish stocks), slow response (e.g., forests), confounding influences of non-climatic events (e.g., wildlife population changes), and, of course, the impact of human management (e.g., grazinglands and fisheries). Greater effort is needed to isolate climate influences in these areas.

Climate and Resource Flows

Quantitative modelling of primary resource production is especially well developed for certain crops (especially small grains; Nix, 1985), freshwater runoff (Beran, 1986), and for energy use (Jager, 1985). Some progress has also been made in modelling climate influences on grasslands productivity (Le Houerou, 1985). Most primary production models are based on correlation between variables assumed to play a role in the resource flow (stochastic models), while others are based on the processes by which mass and energy interact to create resource flows (deterministic or physical models).

Some of these models have been used to project impacts of future climate change. For example, Waggoner (1983) projected shifts in spring wheat yields that might be associated with a warmer and drier greenhouse-perturbed climate in North Dakota. Cohen (1986) used a water balance model of the Great Lakes basin in a similar effort. But, models of climate impacts on resource flows have had little spatial component and have not addressed second-order effects or systemic adjustments like farm abandonment, shifts in the location of resources or related activities, and other land-use changes.

Climate and Land Change

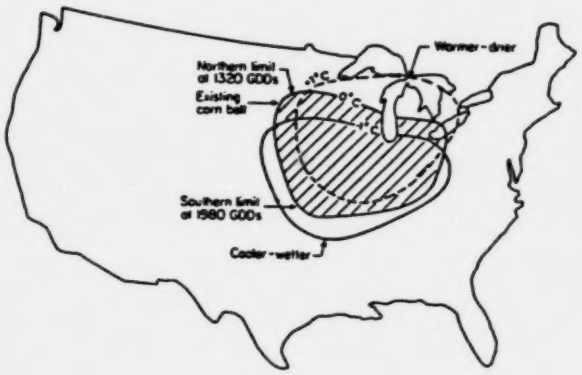
A few studies have attempted to link climate fluctuation to land-use or land cover change. For example, Parry (1978) developed a simple model relating temperature to agricultural production, and then mapped areas where agricultural risk was increased enough to cause field abandonment in England during the Little Ice Age. His approach of mapping the shifts of a "risk frontier" (frequency of crop failure) tied to certain climate conditions recognizes that impacts are the result of both climate change and social sensitivity/response.

Taking a broader focus, Emanuel et al. (1985) mapped Holdridge Life-Zones for the globe, and then altered temperatures in accord with the output of a global circulation model simulating doubled CO_2 content of the atmosphere. Their greenhouse map of global vegetation patterns indicates especially dramatic shifts in the high latitudes; for instance, virtual disappearance of the Boreal Forest. This, and other simulations of spatially contiguous biomes (Solomon and West, 1985), represent important steps towards more integrative modelling of climate impacts on the biosphere.

Modelling of this sort is meant to suggest the extent of potential change rather than to act as actual predictions of change. Most projective impact assessments do not incorporate non-climatic or management factors that may affect how terrestrial systems respond to changing climate. But, the changes they portend give cause for greater attention to potential land changes. Several analyses of the potential greenhouse shift of the United States "corn belt" follow the approach of developing statistical links between climate and the existing range of corn production, and then mapping a future range based on a selected climate projection (Figure 11.1).

It is unlikely that the future "corn belt" will really mimic these projections for several reasons. First, the climatic factor itself is likely to be poorly described (modelled). The main corn growing area of the upper-Midwest is probably best conceived of as a collage of different climate sensitivities, as mapped in Figure 11.2. Climate "events", such as dry periods or frosts, are probably a better determinant of corn production frontiers than are mapped average values of temperature and precipitation. In addition, the current location and shape of the corn growing region are not the result solely of climate, but may be as much related to competing land use, other environmental factors (e.g., soils), and, of course, the historical and substantial role of government intervention in supporting and stabilizing grain production.

FIGURE 11.1: HYPOTHETICAL SHIFT OF THE US CORNBELT[1]



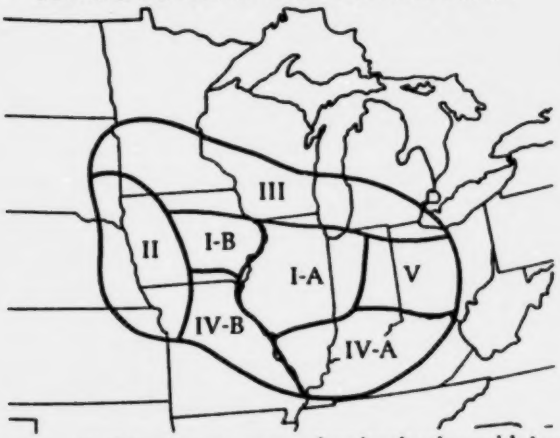
[1] Based on a future increase in frostfree growing season degree days.

After Newman, 1980

Comprehensive Modelling

Some models make multiple linkages within a primary resource realm. For example, the Erosion-Productivity Impact Calculator (EPIC) model analyses soil erosion as part of the biophysical and socio-economic components of agricultural production at the national level (Williams et al., 1983). A few attempts have been made to link primary models (e.g., crop production models) and secondary models (e.g., broader econometric, or other sectoral -- e.g., labour models) to form a chain of impact assessment. This approach was used in a series of climate impact studies sponsored and soon to be published by the United Nations Environment Program and the International Institute for Applied Systems Analysis (UNEP/IIASA) (Parry and Carter, 1985). Anderson (1979) assessed the impact of drought on the Australian economy

FIGURE 11.2: DETAILED BREAKDOWN OF CLIMATE SENSITIVITIES IN THE US CORNBELT



I-A Stable climate, corn planting begins mid-April
I-B Stable climate, planting begins late April
II Precipitation drought and late springs
III Frost, early and late
IV-A Soil drought
IV-B Soil and precipitation drought
V Soil compaction and planting delays

Note: A climate shift would probably cause more distinct shifts than suggested in Figure 11.1.

by beginning with crop yield models and working up through national econometric models that linked economic sectors. Others have linked regional climate-crop models to global models of world food trade (see Robinson [1985] for a review).

THE VALUE OF MODELLING IN CLIMATE IMPACT ASSESSMENT

Most studies thus far linking climate change to terrestrial resource shifts should not be considered predictions *per se*; they mostly lack consideration of many of the variables we know to be important in locational and strategic aspects of resource management. Furthermore, they require more detailed and reliable climate predictions than are currently available, or are even likely to be available in the next several years. But, they do offer insight and guidance for improving our understanding of climate impacts on natural and social systems. While we should not rely on them as actual predictions, they may be useful in the same way that Robinson (1985) felt that global simulation models should be used.

1. To organize existing data in such a way that it provides new insights and facilitates new interpretations.
2. To pose new questions and call for new data, providing the template for collecting and verifying critical measurements.
3. To provide a focus for multidisciplinary and collaborative studies of climate impacts.

In addition, models can also be useful tools for policy analysis when employed to generate "scenarios". For example, simulations of future conditions may:

1. draw policy maker attention to climate impacts,
2. "stoke the imagination" of researchers and decision makers, and
3. suggest policy options.

It is in these roles that emerging modelling capabilities can best be applied to climate impact assessment, and to mitigating the potential impacts of future climate changes.

ACKNOWLEDGMENT

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12

EXPERIENCES IN MODELLING WATER AND LAND RESOURCES WITHIN A CLIMATE CHANGE FRAMEWORK[1]

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ABSTRACT

Concern over increasing concentrations of atmospheric CO_2 and other trace gases has increased in recent years. Atmospheric modellers have provided a possible scenario of the earth's future climate that would be significantly warmer than today's. The impacts of this projected climatic change may be quite significant, but the quantitative assessment of such impacts, particularly at the regional scale, has only just begun.

The purpose of this discussion is to describe some recent modelling of impacts of future climatic change on water and land resources at the regional scale. This is not an exercise at developing new theories. Rather, it is a research effort which utilizes the best available knowledge (models, data, etc.). For example, a recent attempt at regional water resources modelling involved the application of well-known climatic water balance and lake evaporation models. Relationships between climate and snow cover were used to project impacts on skiing. Models of hydro-electric power production, shipping, crop yield, and water consumption have been utilized to project impacts in these areas.

The key element in this exercise is that climate is being considered as a variable, rather than a constant. In certain cases, such as water resources, existing models could already use climate data directly to perform the required calculations. Other models (e.g., shipping) could only use data on a parameter affected by climate (e.g., lake levels) which had to be projected separately. These latter models were thus using climate data indirectly.

A major obstacle to regional modelling is the mismatch of scales between global climate model resolution and the detail needed for such projects as regional land classification or net basin supply calculations for individual watersheds. This requires some interpolation of the climate model outputs, including the use of existing station data to provide a "higher resolution" projection of the "Greenhouse Effect" climate.

Results of an interdisciplinary pilot study on the impacts of CO_2-induced climatic change on the province of Ontario are briefly presented. A scenario derived from a General Circulation Model, developed by the Goddard Institute for Space Studies in the United States, was used. Net basin supply and lake levels in the Great Lakes are projected to decrease. Impacts include losses in hydro-electric power production, shipping, skiing, and agriculture. However, there would be savings due to reduced demand for space heating, and gains in summer recreation.

INTRODUCTION

Doubling of atmospheric concentrations of CO_2 from pre-Industrial Revolution levels (270-290 ppm) is projected to occur in the middle of the 21st century (Kellogg and Schware, 1981; World Meteorological Organization [WMO], 1986). Increases in atmospheric concentrations of other radiatively active gases, such as methane, have also been observed, and are likely to continue. These changes are expected to cause major global warming of 1.5-4.5^{o} C (United States National Research Council [US NRC], 1982; WMO, 1986).

The above projection of climate warming is based on a consensus of a number of atmospheric researchers, who have performed "experiments" using global-scale General Circulation Models (GCMs). Others have used historical analogues of warm periods for the same purpose. Results have tended to show weaker temperature increases, with some decreases at certain locations or seasons of the year.

Climate impact studies have used the results of GCMs and analogues, as well as hypothetical cases. As one would expect, the results are not identical for each scenario. However, in some cases, tentative conclusions have been reached regarding the direction of impact.

In 1984, Environment Canada initiated an interdisciplinary pilot study to investigate the potential impact on Ontario of a climate scenario which might be anticipated under a doubling of CO_2 concentrations. A GCM scenario was used. The objectives of the pilot study included:

1. an assessment of the current capability to gauge the direct and indirect impact of potential climate change on the biophysical environment, natural resource dependent activities and their subsequent interdependencies, and
2. a demonstration of the increasing importance of climate information for long-range planning and decision making regarding natural resource management and related socio-economic strategies.

The purpose of this presentation is twofold:

1. to review the various types of climate change scenarios that are available, as well as their application to impact studies, and
2. to discuss the procedures and results of the Environment Canada pilot study of the potential impacts of climate warming on Ontario.

CLIMATE CHANGE SCENARIOS

Scenarios from Atmospheric Models

Global scale GCMs represent an ambitious attempt to simulate global weather/climate patterns. Simpler atmospheric models, such as radiative-convective models and one and two-dimensional energy balance models do not include certain aspects of climate, such as horizontal transport of heat, and land/sea contrasts. GCMs are three-dimensional integrations of the fundamental equations for conservation of momentum, heat, and moisture, and all aspects of the climate system are included.

However, many assumptions and parameterizations are required, and these lead to uncertainties in the modelling process. As a result, GCMs do not perfectly simulate the present climate, and there are differences between the various GCMs' components and subsequent projections of future climate. When the initial parameterizations are modified by doubling atmospheric concentrations of CO_2, any errors inherent in the initial model runs would probably occur in the 2 x CO_2 simulations. Detailed reviews of atmospheric models, including GCMs, can be obtained from MacCracken and Luther (1985).

Model output is generally expressed as anomalies from present "normals". However, at present, neither the 1 x CO_2 model run, nor the normals are in complete agreement with normals obtained from Canadian and United States station data. In 1984, the Canadian Climate Centre produced modified scenarios by adding the 2 x CO_2 anomalies

to normals estimated for each grid point from isoline maps based on actual station data.

Historical Analogues

An alternative approach to producing numerical models, such as GCMs, is to use past warm periods as analogues of a future warm climate. The fundamental assumption of historical analogues is that the general circulation system of the atmosphere will respond in a similar way to different forcing mechanisms, provided that the boundary conditions (oceans, land, ice surfaces) remain the same. In the case of CO_2-induced climate warming, the assumption is that when heat is added to the lower atmosphere, the resulting changes in circulation patterns will be similar, irrespective of the cause of the heating effect (Palutikof et al., 1984). In other words, it does not matter if the heating occurs because of additional CO_2, increased solar radiation, or some other event.

The advantage of analogues, particularly those derived from recent instrumental records (as opposed to geological evidence, historical documents, or other proxy data sources) is that sufficient detail is available to produce seasonal scenarios for individual continents. The major disadvantage is that observed differences between recent warm and cold years are much smaller than the warming projected by GCMs. Palutikof et al. (1984) interpreted these scenarios as being indicative of conditions during the early phase of CO_2-induced warming, rather than a doubling of CO_2 concentrations.

A set of eight analogue scenarios of Canadian climate, using a similar approach, were recently constructed by Brown and Walsh (1986). These eight cases represent either blocks of years, or several individual years, in which the temperature difference between the warmest and coldest blocks/years were assumed to represent scenarios of future warming. Although annual temperatures increase in all cases, some scenarios exhibit cooling in individual seasons. GCM results do not indicate season cooling, though some locations show cooling in individual months.

Hypothetical Scenarios

Hypothetical warming scenarios can be defined at the discretion of the modeller. General practice has been to make these as simple as possible. For example, the modeller could assume that every month of the year experiences the same warming and the same change in precipitation. A recent study of a river basin in the western United States utilized ten such scenarios, as well as GCM output (Gleick, 1986).

As a tool for sensitivity analysis, hypothetical scenarios represent a useful baseline reference when a number of atmospheric models and analogues are being compared. For example, in terms of impacts on streamflow or land classification, it may be possible to say that a particular analogue is equivalent to a hypothetical warming of $+1^{o}$ C, with a 10 per cent decrease in precipitation.

USE OF SCENARIOS IN IMPACTS MODELLING

Mismatch of Scales

One problem that must be overcome when applying climate change scenarios to regional impacts studies is the relatively coarse spatial resolution of the scenarios' outputs. For example, the Goddard Institute of Space Studies (GISS) model's output was originally provided for 8^{o} x 10^{o} grid squares. There is large subgrid-scale topographic variations, such as mountain ranges or coastal zones. The original GISS output has been modified in order to produce a denser array of grid points, 4^{o} x 5^{o}, but the problem remains.

Considerable interpolation may be required in order to overcome the scenario's coarse resolution. A recent study by Crowe (1985) used present normals from operating stations to estimate snowfall changes for 173 grid points in southern Ontario, although there are only 6 grid points in or near the area. Interpolation using present normals forces us

to assume that local synoptic conditions will not significantly change in the future (e.g., timing and frequency of weather types). Is it possible that the future regional climate will include fewer episodes of frontal passage and increased convective activity? Would that alter the spatial distribution of precipitation in this region?

Another important "mismatch of scales" is the fact that climatic events may not take place at the same temporal or spatial scale as the social or ecological phenomena being studied. Clark (1985) points out that certain ecological processes, such as vegetation range extension, occur at longer time scales and smaller space scales than the projected "Greenhouse Effect" warming. Other processes, including biomass accumulation, occur on much shorter time scales, and are therefore likely to adapt to prevailing conditions.

Impacts studies often proceed by imposing an instantaneous climate change on present crops, vegetation, socio-economic systems, etc. Clark suggests that for processes that can adapt on a short time scale, such as crop growth, a more appropriate method for assessing the impacts of long-term climatic change would be to look at changes in indices of agricultural potential, rather than changes in yield of specific crops. For slower ecological processes, Clark notes that the likely responses would probably lag behind the climatic warming scenario being considered here. Unlike the case of crop yields, the climate change would be instantaneous relative to the rates of vegetation range extension.

Assumptions for Data Estimates

Most scenarios provide monthly or seasonal data on changes in temperature and precipitation. A large number of other variables can be obtained from GCMs, including wind, pressure, and humidity. All of these may not be available from the analogue scenarios due to lack of data in the instrumental record, particularly in remote areas such as the Arctic. Analogues based on recent years (post-1945) are more likely to include such data.

The above scenarios, after they have been modified by using normals based on station data, should contain features of the regional climate. These features would not have appeared in the GCM 1 x CO_2 model runs. However, there are certain variables that cannot be directly produced by the scenarios because of their coarse resolution.

In recent studies on water resources in the Great Lakes Basin (Cohen, 1986 and 1987b), it has been necessary to calculate evaporation loss for the five lakes. Projections of lake surface temperatures, a requirement of the evaporation model being used, could not be directly obtained from any scenario. For the purpose of that study, it was assumed that lake temperatures would increase at the same rate as the projected increase in air temperature at the nearest grid points. An exception was those months when the normal lake temperature was near 0.0° C, in which case, smaller increases were assumed.

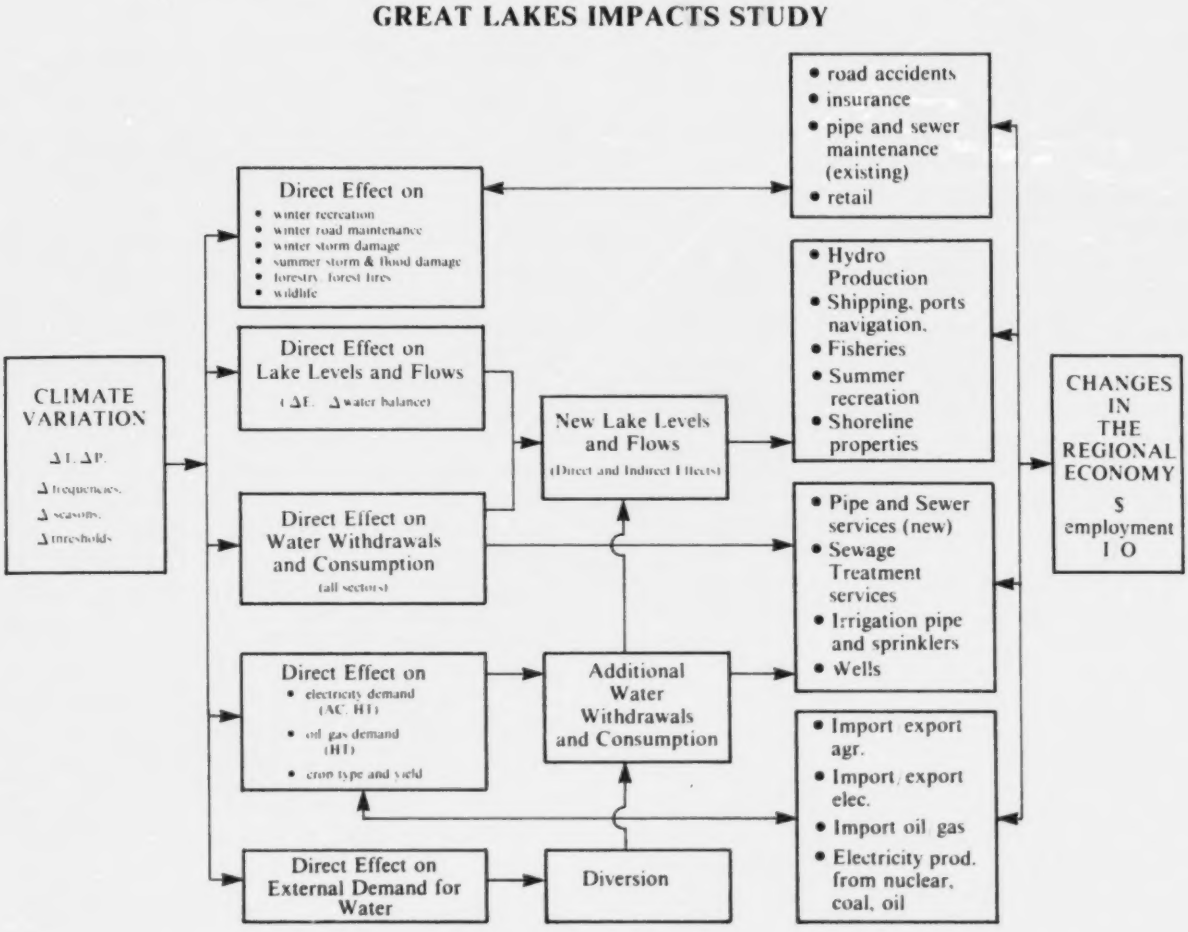
Other elements that would probably require modifications include soil temperatures under various surface covers (forest, grass, etc.), dew point temperatures over lakes, and ice cover. These may be estimated as above, or by some type of statistical method, such as linear regression with air temperature. The latter was tried in order to estimate Great Lakes ice cover (University of Windsor, 1986).

PILOT STUDY OF IMPACTS IN ONTARIO

Description of Working Group

A draft framework for an impacts study of the Great Lakes Basin (Figure 12.1) was recently proposed by Cohen (1986). Several key biophysical and socio-economic sectors were identified as having links with climate variation in this region. Concurrently, a pilot study on impacts of CO_2-induced climatic change on Ontario was undertaken and has recently been completed (Allsopp and Cohen, 1986). It was coordinated by the

FIGURE 12.1: INTERCONNECTED COMPONENTS OF CLIMATE IMPACTS AND SOCIETAL RESPONSES WITHIN THE GREAT LAKES REGION



Note: Δ = Change
T = Temperature
P = Precipitation
E = Evaporation
AC = Air Conditioning
HT = Space Heating
I/O = Inputs/Outputs

Source: Cohen (1986)

Ontario Region of the Atmospheric Environment Service (AES), under the sponsorship of the Canadian Climate Program. Participants included academics, government scientists, and private consultants. The pilot study, which used the GISS scenario, examined climate system components and resource uses (Table 12.1). These are discussed in the following sections.

It should be noted that the emphasis of this regional study is on the approach and process rather than a forecast of the future. Given the uncertainties of future climate projections, precipitation patterns in particular, it would have been preferable to undertake impact analyses of a range of scenarios with a view to exploring possible regional opportunities and losses arising from climate change. However, resource constraints precluded this approach. The study was constrained somewhat by the necessity to use or adapt, with many underlying assumptions, existing models, methodologies or techniques to ascertain biophysical and socio-economic impacts. Where models were not available, qualitative assessments were conducted.

The Climate Scenario

The GISS model output was originally generated for an 8^{o} latitude by 10^{o} longitude grid square spacing. This output was modified by W. Bach, University of Munster, West Germany resulting in a 4^{o} by 5^{o} spacing of grid points (Figure 12.2). The output consisted of monthly values of temperature and precipitation for 1 x CO_2 and 2 x CO_2 climates. The 2 x CO_2 - 1 x CO_2 temperature and precipitation anomalies were combined with current normals from station data to arrive at a 2 x CO_2 normal.

The modified GISS scenario projects a 4.3^{o} C to 4.9^{o} C increase in mean annual temperature in the Great Lakes Basin, with winter temperatures increasing by 5.2^{o} C to 5.9^{o} C, and summer temperatures by 2.8^{o} C to 4.3^{o} C. The mean annual precipitation in the basin changes by +13.6 per cent northwest of Lake Superior to -4.2 per cent southeast of Lake Ontario. Precipitation increases are projected for all seasons, except the September-November period in the southern and eastern part of the basin.

Impacts on Water Resources

Numerical models and study methodologies currently used by the Inland Waters Directorate, Ontario Region were adapted by Southam and Dumont (1985) to assess the impact of the modified GISS scenario on Great Lakes levels and flows. This required estimates of net basin supply (NBS). It is assumed that:

$$NBS = Pw - Ew + Q$$

where Pw is overlake precipitation,
Ew is lake evaporation, and
Q is runoff from the lake's drainage basin.

All elements are expressed in units of discharge, cubic metres per second (CMS). Groundwater and existing diversions were assumed to be negligible at this scale.

Monthly Pw was calculated for both present and GISS conditions using lake/land precipitation ratios ranging from 1.00 on Lake Superior to 0.92 on Lake Ontario. Monthly Ew obtained from Cohen (1986) was computed using a mass transfer approach, in which the vertical movement of water vapour to and from the lake surface is a function of the atmosphere-lake vapour pressure gradient and the wind speed. It was assumed that wind speed remained unchanged from present normals, and lake temperatures and dew point temperatures increased by the same amounts as the ambient air temperature. An exception was those months where the normal temperature of the lake surface was near 0.0^{o} C, in which case, smaller increases in lake temperature were assumed.

The runoff to each lake was estimated using a modified version of a hydrologic model based on water and energy balances (Witherspoon, 1970). Regional moisture is computed as precipitation minus actual evapotranspiration. Runoff for a particular month is

TABLE 12.1: LIST OF INDIVIDUAL SECTOR STUDIES

TOPIC	QUANT/QUAL	$	PARTICIPANT
Climate System			
Streamflow	QUANT		IWD (with AES)
Net Basin Supply			
Lake Levels			
Water Quality	QUAL		IWD
Wetlands	QUAL		Wall et al.
Snowfall	QUANT		AES
Air Quality	QUAL		AES
Solar Energy	QUANT		AES
Resource Use			
Electricity Demand	QUANT	$	University of Windsor
HT and AC Demand	QUANT		AES
Hydroelectric Power	QUANT	$	University of Windsor
Shipping	QUANT	$	University of Windsor
Agriculture	QUANT	$	LEG
Tourism and Recreation	QUANT	$	Wall et al.
Municipal Water Use	QUANT		AES
Forestry	QUAL		CFS
Health	QUAL		Workshop

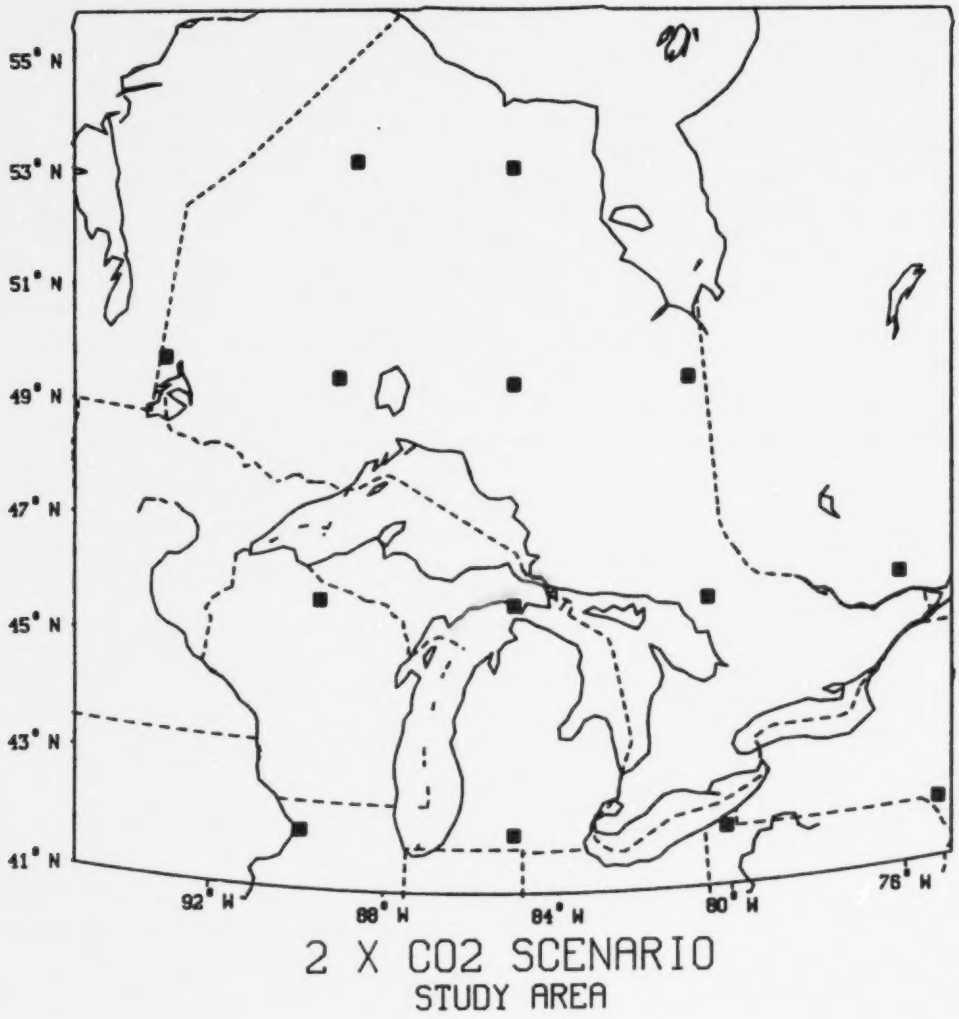
Note: IWD = Inland Waters Directorate
AES = Atmospheric Environment Service
LEG = Land Evaluation Group
CFS = Canadian Forestry Service

then a function of the regional moisture that month, and the regional moisture and runoff of the previous month.

Present normal NBS calculated by the above method compared quite favourably on a lake by lake and overall basis with recorded supplies. The overall NBS change resulting from the GISS was -14.9 per cent, although lake by lake changes vary considerably. A related NBS study conducted by Cohen (1986) using a modified Thornwaite water budget technique resulted in an estimated NBS change of -20.8 per cent.

Great Lakes water levels and flows are functions of NBS, inflows from an upper lake, diversions, etc. Each of these factors are functions of regulation plans, winter ice flow retardation, etc. These relationships were used to determine the effect of the GISS scenario on lake levels and outflow. First, a basis of comparison (B-O-C) period of 1900-1976 was selected. The mean recorded NBS was approximately equivalent to the 1951-1980 period. The historic Great Lakes levels and outflows could not be used as the B-O-C because they included changes over time such as diversions, alterations in the connecting channels, and erection of control structures at the outlets of Lakes Superior and Ontario. Therefore a uniform set of present conditions as adopted by the Lake Erie Water Levels Study (International Joint Commission [IJC], 1981a) were selected. These include present outlet regimes, methods

FIGURE 12.2: STUDY AREA WITH THE GISS GRID POINTS



of regulations, and diversions into and out of the system. The monthly level and outflow for each lake under the B-O-C were obtained by routing through the system the recorded NBS, assuming a regime defined by the above set of conditions. Therefore, the B-O-C is the levels and flows that the Great Lakes - St. Lawrence System would have experienced for the period 1900-1976 had the present set of uniform conditions been in effect.

Next, the actual NBS data for the 1900-1976 period was modified by differences established for each lake by month in order to estimate NBS data for the GISS scenario (Table 12.2). The use of a 77-year period dampens the effect of not knowing the starting elevation

TABLE 12.2: GREAT LAKES MEAN MONTHLY LEVELS (METRES) AND OUTFLOWS (CMS)

	BASIS OF COMPARISON		GISS		GISS + CONSUMPTIVE USE	
	Level	Outflow	Level	Outflow	Level	Outflow
Superior	183.01	2204	182.80	2209	182.71	2198
Michigan-Huron	176.26	5236	175.67	4599	175.43	4357
St. Clair	174.83	5347	174.35	4689	174.10	4447
Erie	173.97	5867	173.53	5086	173.29	4642

Adapted from Southam and Dumont (1985)

of the lakes. Subsequently, a new set of levels and flows was estimated by routing the GISS scenario NBS through the system. Ice retardation assumptions were not significant when compared to NBS changes. A further scenario was developed, this time using an IJC most likely projection for increased consumptive uses for 2035 (IJC, 1981b). Results are shown in Table 12.2. No levels and flows estimates were made for Lake Ontario because simulation runs show that the current regulation plan for Lake Ontario cannot address the large decreases in NBS projected under the GISS scenario. The significance of the levels generated is reinforced by the University of Windsor (1986) analysis that low levels experienced during 1963-1965 on Lakes Michigan-Huron could be expected 6 per cent, 44 per cent, and 59 per cent of the time, respectively, under B-O-C, GISS, and GISS plus consumptive use conditions.

Further work is required to estimate Lake Ontario levels and outflows under 2 x CO_2 climate conditions. Also, subsequent to evaluation of impacts, new regulation schemes should be tested to ascertain how well they could cope with climate change.

Results of studies on ice cover revealed that significant decreases could occur in the Great Lakes Basin. The University of Windsor (1986) used a Weather Severity Index (WSI), based on mean overlake temperature during November-February, to estimate ice cover by regression analysis. The analysis showed that ice would disappear from all lakes, except Erie. The Erie results, however, are not considered realistic.

Two separate studies on snow (Crowe, 1985; Wall et al., 1985) both projected significant decreases for the region. The studies used were based on relationships between temperature and snow variables. For example, total winter snowfall was estimated by finding a relationship between mean monthly temperature and the percentage of total precipitation falling as snow. The length of snow cover season was inferred from winter snowfall, using data from Crowe et al. (1977) for lake effect areas and sites away from these effects. Snow cover suitability for skiing was defined by determining the per cent probability of a day with a snow cover of at least 5 cm, no measurable liquid precipitation, and a maximum temperature of less than 4.5^{o} C. Snow cover was "marginally reliable" if the percentile exceeded 50 per cent.

Crowe's (1985) study showed snowfall decreases of 40 - 50 per cent in the snowbelt areas of Lake Huron and Georgian Bay, 60 - 70 per cent along the north shore of Lake Ontario

and throughout the Niagara Peninsula, and 60 - 90 per cent in southwestern Ontario. The snow season would decrease 4 - 6 weeks in southern Georgian Bay, and all of southwestern Ontario would experience a "zero snow season". Projected changes in snow season from Wall et al. (1985) were larger due to slight differences in methodology.

Impacts on Land Resources

The socio-economic impacts of CO_2-induced climatic changes are difficult to quantify because it is very probable that technology and other external factors will change with time. The direction of the impact in each sector (i.e., gain or loss), is somewhat easier to predict than the magnitude, but even here, societal reaction to climatic change may create a new climate-economy "production function", differing from models based on present conditions.

Socio-economic impacts in a number of sectors are listed in Table 12.3. Some of these are expressed in dollars using existing models. References are indicated in Table 12.3. Impacts are largely negative, particularly in agriculture, winter recreation, shipping and hydro-electric power production.

Michael Brklacich (LEG) describes the agriculture study in more detail in Chapter 13. Briefly, the study assumes that available land is fixed to current values. If so, the productive capacity of Ontario's land resource is 66 per cent greater than current production levels. Under the GISS scenario, this is reduced to 60 per cent. The equivalent dollar loss indicated in Table 12.3 (unpublished estimate) has to be qualified since it reflects reduction in production levels due to climate change relative to existing regional patterns of land use and crop production.

The forestry study was a qualitative assessment, however, quantitative work is in progress in other areas. In particular, a preliminary assessment on forest fire potential (Stocks and Street, 1987) indicates that the concept of increased length, increased severity, and modifications of the temporal distribution of fire severity during the fire season are plausible, considering the GCM scenarios' output. This type of study is in line with Clark's (1985) suggestion that impact studies using indices would be particularly valuable in the context of the Greenhouse Effect.

For the purpose of this discussion, it is also useful to review the results of the wetlands study (Wall et al., 1985). This was a qualitative investigation of potential impacts on Point Pelee National Park on Lake Erie's north shore, and Presqu'ile Provincial Park on Lake Ontario's north shore. Both have large areas of marshland, and are accessible to a large number of users. However, Point Pelee is a closed marsh, protected from Lake Erie waves by sand spits, while the Presqu'ile marsh is an open wetland system, which can be affected by waves from Lake Ontario. Moisture conditions in both marshes are influenced primarily by lake levels, rather than precipitation or overland runoff.

In this study, an analogue approach was used. It was assumed that the present vegetation characteristics evolved in response to historic conditions (including man-induced changes), that shoreline marshes would benefit from lake level fluctuations (especially periodic flooding), that the same wetland type (closed, open, riverine, etc.) would react similarly to water level changes as it had in the past, and that lake level changes would affect aquatic-oriented wildlife more than terrestrial wildlife, thereby influencing associated recreational activities.

Lake Erie levels under the GISS scenario are projected to drop 44-68 cm. Similar occurrences in the past have had negative impacts on the closed marsh at Point Pelee. The marsh drained, leads to reduced species diversity, and under severe conditions, changes in the waterfowl migrating route. The latter could result in a collapse of the now well-developed hunting and birdwatching industries. Fishing would also be reduced. Marsh fires would increase in frequency, which could destroy the wetland character of

TABLE 12.3: IMPACTS OF CO_2-INDUCED CLIMATIC CHANGE ON THE ECONOMY OF ONTARIO

RESOURCE USE	IMPACT	ANNUAL GAIN/LOSS ($ MILLION CDN)
Electricity Demand (U. of Windsor, 1986)	Reduced winter space heating demand = 6533 to 7840 GWh Increased summer air conditioning demand = 162 to 216 GWh Net reduction = 6371 to 7624 GWh	+99 to +118 (reduced costs to provincial utility) (1979)
Res. Heating and Cooling Demand (Bhartendu and Cohen, 1988)	Reduced space heating demand = -45 per cent Increased summer cooling demand = +7 per cent	+?
Hydroelectric Power (U. of Windsor, 1986)	Reductions due to lower lake levels and flows, except at St. Mary's River. Losses at De Cew, Sir Adam Beck, and Robert H. Saunders power plants. Total loss = 2220 to 4165 GWh, depending on Lake Ontario regulation.	-34 to -65 (1979)
Great Lakes Shipping (U. of Windsor, 1986)	Reduced cargo per vessel due to lower channel depths. Losses are highest if coal shipments greater than present. Losses do not include delays at canal locks due to potentially heavier traffic, and occur despite reduction of ice cover and longer shipping season.	-10 to -27 (1979 $US)
Agriculture (LEG, 1986)	Reductions in crop yield due to increased heat and moisture stress, below potential crop yield due to optimum use of existing available land. This considers positive impacts of extended growing season and northern expansion, but does not consider new crops or irrigation.	-107 (1981)
Tourism and Recreation (Wall et al., 1985)	Greater use of parks and campgrounds due to longer summer and shoulder seasons. Indirect gains would occur in local retail sectors. Eight parks were studied.	+4 (1979)

Continued

TABLE 12.3 (Cont.)

RESOURCE USE	IMPACT	ANNUAL GAIN/LOSS ($ MILLION CDN)
Tourism and Recreation (Wall et al., 1985)	Ski areas in southern Ontario could be eliminated due to reduction in snow season. Small loss or gain could occur in the north, depending on success of competing facilities elsewhere (e.g., Laurentians). Indirect losses would occur in local retail sectors (e.g., Collingwood)	-50 (1985)
	Effects of changes in lake levels, streamflow, and water quality on shoreline properties and wetlands. Possible negative impacts on closed marsh.	?
Municipal Water Use (Cohen, 1987a)	Increased demand of 5 litres per capita per day during May-September, due to warmer summer season. This may also result in increased demand for treatment services, and accelerate the expansion of surface water distribution systems, and replacement of wells in some areas.	-?
Forestry (Stocks, 1985)	During the transition from boreal forest to new hardwood forest types, there would be increased damage due to disease, insects, and fire, and reduction in winter logging operations. Possible benefits could result from CO_2 enrichment.	-?
Health, Air, and Water Quality	Increase in heat stress. Decrease in cold stress. Poorer air and water quality in summer?	?

Source: Allsopp and Cohen (1986)

this small area.

A decline in Lake Ontario levels would shift the open marsh at Presqu'ile towards the receding lake, eventually reaching a new equilibrium. Its integrity as a wetland habitat would probably be preserved since aquatic plants could still find suitable conditions for growth.

CONCLUSION

Recent efforts at modelling water and land resources within a climate change framework have shown that it is possible to utilize

existing models for this purpose, but that a number of intermediate steps are required before quantitative or qualitative results can be obtained. First, look for ways in which climate can be expressed as a variable element in the model. The use of climate indices, such as a fire weather index may be appropriate, as alluded to earlier. Second, consider the spatial and temporal resolution required for modelling, and apply interpolation techniques where necessary in order to overcome the mismatch of scales problems. This includes both the differences in resolution between global climate scenarios and regional climate, as well as the issue of instantaneous versus gradual impacts that may be experienced by various elements in society and nature.

Although the impact assessments referred to herein were largely sectoral in reality, this regional pilot study did attempt to look at interdependencies and possible mitigation strategies, at least in a first-order sense (Allsopp and Cohen, 1986). In addition, the study provided an opportunity to assess data requirements, and the applicability or capability of currently available models, methodologies, and techniques to delineate impacts. Beside the limitations of the climate scenarios, the study also confirmed that we still require further knowledge about regional physical processes, such as precipitation over the lakes, as well as interactions of climate with a number of other environmental elements, such as streamflow, air and water quality. More in-depth assessments of potential physical and socio-economic impacts, associated feedback processes and response strategies, with greater emphasis on an interdisciplinary approach, are required in the increasingly important subject area of climate impact assessment.

NOTES

1. This paper includes excerpts from Allsopp and Cohen (1986).

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13

EFFECTS OF CLIMATIC CHANGE ON AGRICULTURAL LAND RESOURCE POTENTIAL

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ABSTRACT

Recent studies have indicated that profound shifts in climatic conditions might occur over the next 100-year period (e.g., the "Greenhouse Effect"). These studies have prompted resource analysts to consider the extent to which these changes in climate might affect society. Such assessments are especially relevant to the agri-food sector where primary production is to a large degree dependent upon climate.

This study estimates the extent to which a doubling in atmospheric CO_2 might affect food production opportunities throughout Ontario, Canada. It assesses the possible impacts of a CO_2 doubling on:

1. agroclimatic resources,
2. crop productivity levels, and
3. economic suitability of land resources for crop production.

The analysis is facilitated by a land modelling system with which it is possible to evaluate implications of environmental (and other) changes on the distribution of land resources for food production.

The specified changes in climate would imply a more favourable climate for crop production in the northern portions of Ontario. A wider array of crops could be grown and forage yields would increase. Production opportunities for crops currently grown in the southern parts of Ontario would be diminished. Overall the specified changes in climate would reduce the biophysical prospects for crops currently grown in Ontario.

INTRODUCTION

Results from models which simulate atmospheric conditions along with climatic records have contributed to a general consensus that a global warming is likely (Hare, 1985). There is however no agreement on the extent to which temperatures might increase at specific locations, and even less is known about associated shifts in other climatic parameters such as precipitation, wind speed and direction, and cloud cover.

The prospect of substantial yet uncertain changes regarding future climates has stimulated considerable interest in the interactions between climate and society (Riebsame, 1985), and in the extent to which climatic change might trigger adjustments in human activities (Chen et al., 1983; Kates et al., 1985). These sorts of assessments are especially relevant to the agri-food sector where primary production is, to a large degree, climate dependent.

This paper provides an overview of the first phase of a study investigating the biophysical and socio-economic implications of climatic

change on food production opportunities throughout the province of Ontario, Canada. This first phase evaluates the possible impacts of CO_2-induced climatic warming on the agricultural land resource potential. The research was conducted at the University of Guelph for the Atmospheric Environment Service (AES), Environment Canada. It employed a land evaluation system developed for Ontario by the Land Evaluation Group (LEG) (LEG, 1983; Smit et al., 1984) and involved collaboration with scientists at the AES and Agriculture Canada.

The next section provides an overview of the development and structure of the Ontario land evaluation system. The third section outlines the research strategy employed in this study, and the components of the Ontario land evaluation system which are used in subsequent analyses. The fourth section highlights some of the major findings. The research strategy, data sources and assumptions, analytical procedures, and research findings for Phase I are presented in greater detail in LEG (1985). The paper concludes with a discussion of the policy implications of climatic change and suggestions to guide future impact assessments.

AN OVERVIEW OF THE ONTARIO LAND EVALUATION SYSTEM

By the mid-1970s, it was apparent that information on the biophysical qualities of the resource base was not being employed effectively in the policy formulation process. In retrospect, it would appear that there were at least two reasons for this underuse of environmental data and analytical procedures. Information compiled by scientists from the biophysical disciplines was in most instances presented and packaged in a format that was not readily understandable to public decision makers. Scientists would painstakingly prepare inventories of basic physical properties of the resource base and appraise the impacts of external stimuli such as farming practices on these properties. While this careful characterization of the resource base has certainly contributed to our understanding and appreciation of the biophysical environment, it has proven to be more difficult to find ways to apply this sort of information in the policy arena. This does not suggest biophysical scientists were negligent, but rather, it merely acknowledges that there was a considerable gap between the activities of the scientific community and those of the policy formulators.

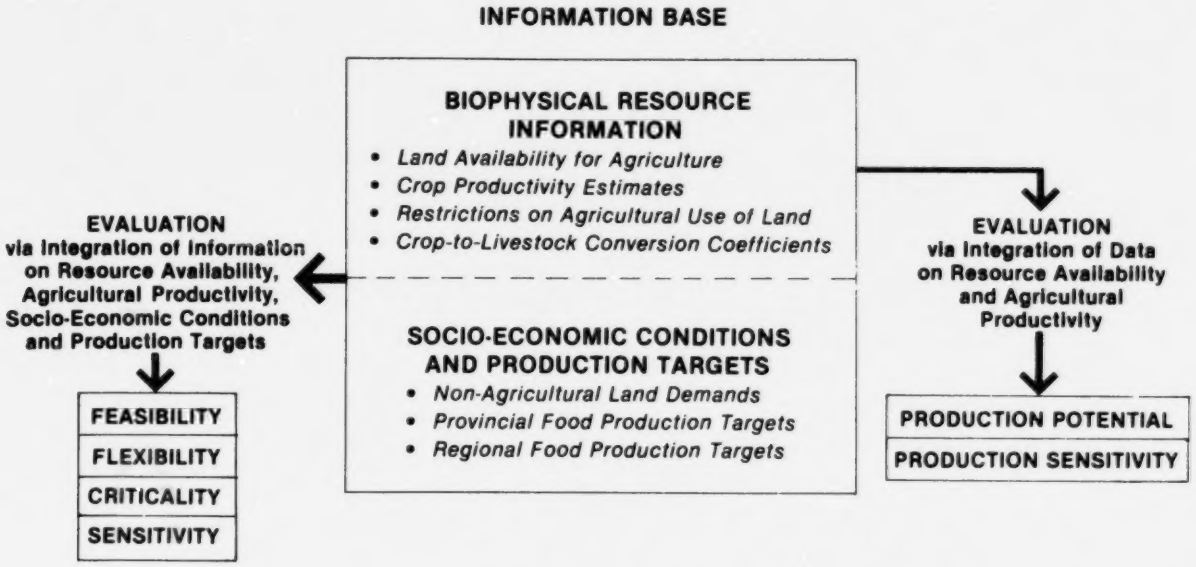
Another reason for the sparing use of biophysical data in the policy development process was that these information sources did not relate directly to public issues concerning long-term use and adequacy of the resource base. In the agri-food sector, some of the more important policy issues related to the following.

1. What are the current options for resource use?
2. How might these production opportunities be affected by urban expansion, environmental degradation, new technologies and other changes?
3. Under which conditions can long-term requirements for food production be met?
4. Under which conditions might there be short-falls in agricultural production?

It was with these sorts of questions and concerns in mind that the rudiments of a land evaluation system for Ontario (LEM 2) were developed. The LEM 2 system was designed and implemented by the University of Guelph's Land Evaluation Group. Primary support was provided by the Land Resource Research Centre, Agriculture Canada, with additional support and cooperation from the Regional Development Branch, Agriculture Canada; Lands Directorate and the Atmospheric Environment Service, Environment Canada; and the Ontario Ministry of Agriculture and Food.

Figure 13.1 sketches the LEM 2 system. The system consists of two major components: an information base and a family of analytical procedures. A concise description of these

FIGURE 13.1: OVERVIEW OF THE ONTARIO LAND EVALUATION SYSTEM


INFORMATION BASE
BIOPHYSICAL RESOURCE INFORMATION
• Land Availability for Agriculture
• Crop Productivity Estimates
• Restrictions on Agricultural Use of Land
• Crop-to-Livestock Conversion Coefficients
SOCIO-ECONOMIC CONDITIONS AND PRODUCTION TARGETS
• Non-Agricultural Land Demands
• Provincial Food Production Targets
• Regional Food Production Targets
EVALUATION via Integration of Information on Resource Availability, Agricultural Productivity, Socio-Economic Conditions and Production Targets
FEASIBILITY
FLEXIBILITY
CRITICALITY
SENSITIVITY
EVALUATION via Integration of Data on Resource Availability and Agricultural Productivity
PRODUCTION POTENTIAL
PRODUCTION SENSITIVITY

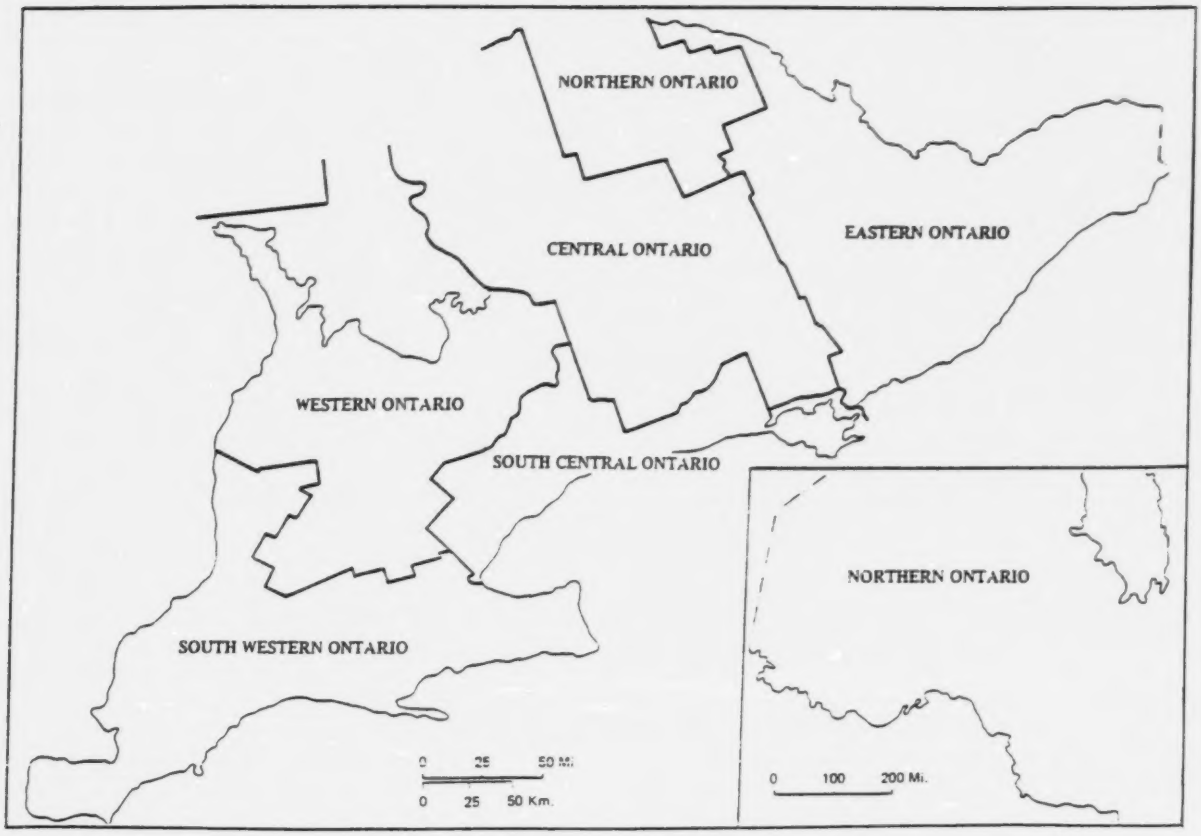
components follows.

Information Base

Several participants in this workshop have already stressed that the foundation of land modelling and assessment is a consistent data structure. This is certainly true for the LEM 2 system. If we can borrow some descriptive jargon from the earlier presentation by Thomas Hoekstra (Chapter 3), our estimates of the availability of land for agriculture are based upon consistently defined "discontinuous homogeneous land units". The specific characteristics which are used to classify Ontario's land resources are, of course, different from those used in the southeastern United States; but nevertheless, both systems adhere to the principal of internal consistency. In the Ontario system, climatic characteristics and municipal administrative areas are interwoven to delineate the six regions outlined in Figure 13.2, and these regions are disaggregated into the seven land types described in Table 13.1. The physical qualities of Ontario's land resources vary considerably over relatively short distances, and hence, a particular land type is not represented by a discrete area within a region. Overall, the discontinuous homogeneous land units employed in the Ontario system are defined according to administrative, climatic and land (soil) characteristics. The supply of land presently cleared and available for agricultural production is estimated to exceed 5.3 million hectares. The LEM 2 system also contains several estimates of the future availability of land for farming.

The crop productivity data sets are fully integrated with the land resource elements of the information base. Productivity models have been implemented for the 18 major crops grown in Ontario. The LEM 2 system stores estimates of the current productivity of each of these crops on each land unit, as well as yield estimates given selected changes in climate, technology and management, soil quality and economic conditions.

FIGURE 13.2: REGIONS IN ONTARIO



Land conservation and hence sustainable productivity levels are incorporated into the LEM 2 system by specifying land-use practices which would control soil erosion and prevent the buildup of pests and disease organisms. These include the rotation of row crops with forages and cereals, and remedial measures such as grassed waterways and windbreaks. This information is stored in data sets pertaining to restrictions on the agricultural use of land.

Crop-to-livestock conversion coefficients link the breeding and production of livestock to the land base via feeding requirements for each of the eight major livestock types raised throughout Ontario. A base data set founded upon current feeding practices is stored, as are other data sets which reflect possible adjustments to livestock production technologies.

Non-agricultural demands for land (e.g. housing, recreation, forestry, etc.) are estimated exogenously, and incorporated into the information base by adjusting the land availability estimates for agriculture.

The final two elements in the information base estimate provincial and regional food production targets. These data are estimated as a function of population growth, consumption patterns, regional development schemes and agricultural trading patterns. Once

TABLE 13.1: OVERVIEW OF THE LAND CLASSIFICATION SYSTEM

LAND TYPE	BIOPHYSICAL CHARACTERISTICS
A	- well-drained loamy soils - relatively level topography
B	- fine-textured clays - moderately well to well-drained
C	- coarser-textured sand and gravel, or shallow soils (less than 1 m to bedrock) - well to excessively well-drained
D	- imperfectly drained soils which have been tile drained
E	- imperfectly drained soils which have not been tile drained, and all poorly to very poorly drained soils
F	- extremely stony or shallow soils
G	- well-drained loamy soils - rolling to hilly topography

Note: Ontario's land resources are classified according to their biophysical characteristics that are relevant to the production of crops.

again, the database contains estimates for current as well as future conditions.

One of the major applications of the Ontario system is to provide data to resource and policy analysts. The data are compiled on a consistent basis for Ontario, and hence it is possible to conduct interregional assessments of resource suitability for crop production. For example, the interpretations from the database can readily address issues such as those which follow.

1. In which regions are there the greatest opportunities for expanding or upgrading the agricultural land base?
2. What is the current productivity of different types of land for particular crops?
3. How sensitive are these productivity levels to specified changes in environmental conditions such as climatic change, land degradation, acid precipitation and artificial land drainage?

Analytical Capabilities

The distinctive analytical capabilities of the LEM 2 system integrate various elements within the information base. Production potential refers to the possible levels of production given specified conditions for land availability, crop productivities, restrictions on agricultural land use and livestock production (Figure 13.1). In other words, it estimates the extent to which biophysical conditions constrain production opportunities at the regional or provincial scale. These assessments can be conducted for individual agricultural activities or for groups of activities. For the latter case, it is also necessary to specify patterns or mixes of

production.

The production potential approach to resource assessment can be used to indicate those regions of Ontario in which there are the greatest opportunities for agricultural production. It can also indicate the sensitivity of these production opportunities to changes in environmental conditions such as artificial land drainage, climatic change, or land degradation.

An alternative approach to resource assessment is to estimate the feasibility of meeting and exceeding specified levels for agricultural production. The procedure utilizes mathematical programming techniques to integrate information on resource availability and productivity with information on production levels and other socio-economic conditions for land use (Figure 13.1).

If it is feasible to meet the specified levels of production given the available land base, estimated productivity levels and so on, the Ontario system also estimates the ease with which these production levels could be met. "Flexibility" measures the gap between production potential and production levels for the agricultural system as a whole. "Criticality" refers to the strategic importance of particular land units for specific crops given specified conditions.

The Ontario land evaluation system can also measure the "sensitivity" of these evaluations (i.e., feasibility, flexibility and criticality) to changes in biophysical and/or socio-economic conditions by making appropriate adjustments to the input parameters (Figure 13.1).

We will now turn to the application of the LEM 2 system to issues relating to the impacts of climatic change on Ontario's resource potential for agriculture. The application employs the land availability and crop productivity elements of the information to gauge the sensitivity to climatic warming of each region's potential for food production. An overview of the research strategy employed for this project is followed by selected findings.

RESEARCH STRATEGY

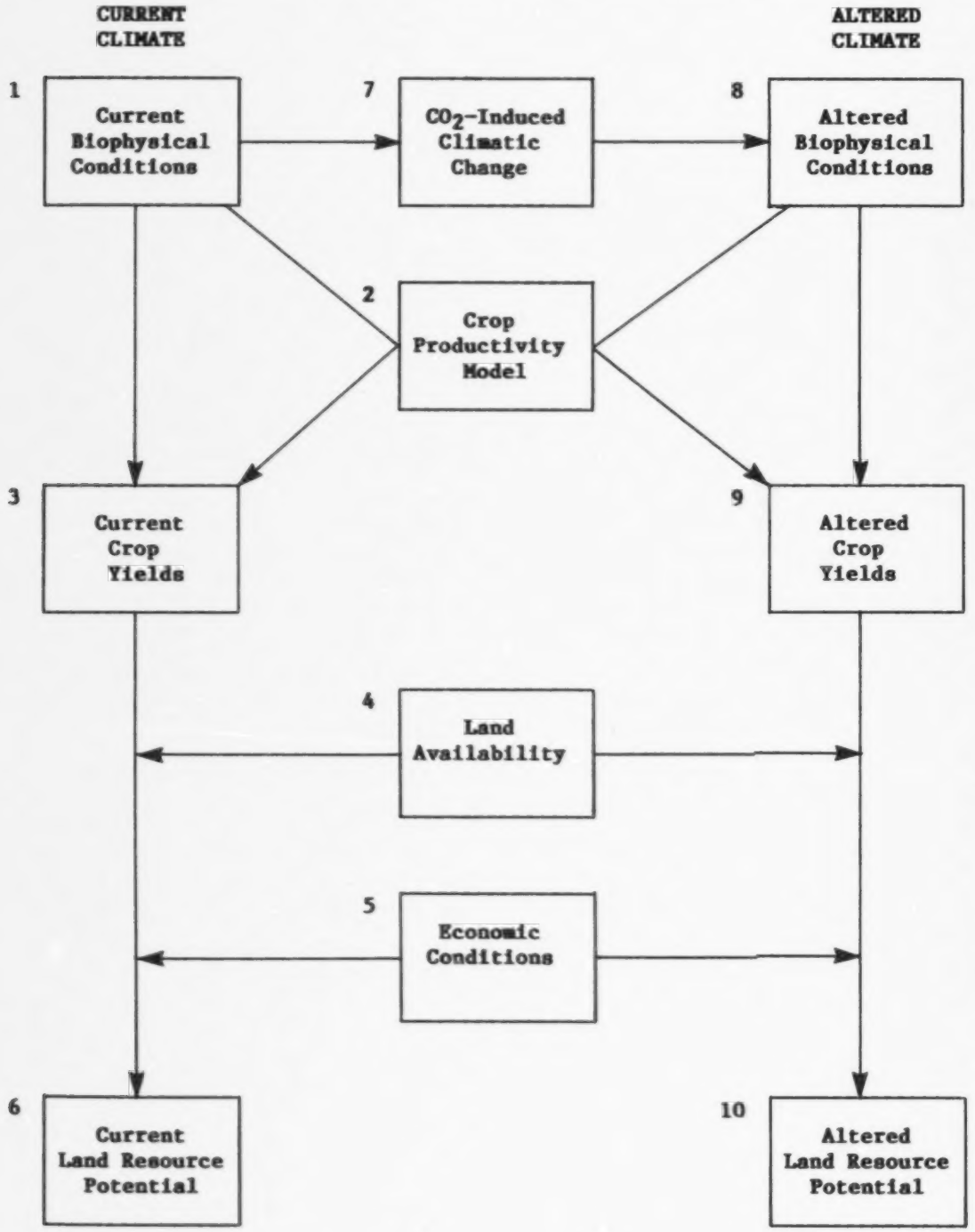
Figure 13.3 summarizes the research strategy for this study. It is designed to isolate the impacts of an environmental change, in this case a change in long-term climate, on crop productivity levels and hence on land resource potential for agricultural production.

The strategy commences with an inventory of current biophysical conditions (e.g., climate, land, water, and so on) (Figure 13.3 - Box 1). A crop productivity model (Box 2) is used to estimate crop yields (Box 3) for a specified set of biophysical conditions. Land resource potential (Box 6) is estimated for particular crops and considers the availability of land for production (Box 4), economic conditions such as costs of production inputs and market prices (Box 5), and yields. Hence land resource potential is used here to estimate economic as well as biophysical opportunities for crop production.

An altered climatic regime is considered by adjusting the specified biophysical conditions. For this particular study, a doubling in atmospheric concentrations of CO_2 is assumed (Figure 13.3 - Box 7) and its effects on agroclimatic properties are estimated (Box 8). It is then possible to isolate the effects of the specified climatic change on productivity levels (Box 9) and agricultural land resource potential (Box 10).

The strategy sketched in Figure 13.3 is employed to estimate the effects of a CO_2-induced climatic warming on Ontario's land resource potential for crop production. Other conditions such as crop production technologies, resource availability, quality of non-climatic resource inputs and economic conditions are held constant. Of course, it would be feasible to consider multiple changes, but the overall purpose of this study is to isolate the effects of an altered climatic regime on agricultural potential.

FIGURE 13.3: STRATEGY FOR EVALUATING EFFECTS OF CLIMATIC CHANGE ON AGRICULTURAL LAND RESOURCE POTENTIAL



CLIMATIC CHANGE AND ONTARIO'S AGRICULTURAL POTENTIAL[1]

Effects on Climatic Resources for Crop Production

The Ontario study employs two scenarios for climatic change provided by the AES. Under Scenario A, estimates of change in monthly norms for mean daily temperature and for total precipitation are derived from a climatic model developed by the Geophysical Fluid Dynamics Laboratory. Data are presented on the basis of grid cells measuring approximately 4.5^{o} latitude and 7.5^{o} longitude, and the nine cells in and adjacent to Ontario are used in this study. Scenario B employs analyses conducted by the Goddard Institute for Space Studies. Once again, estimates of change are provided for monthly norms for mean daily temperature and for total precipitation. The spatial resolution employed under Scenario B is improved somewhat, and a total of twelve data points are used in the Ontario study.

The first challenge in the Ontario study involved transforming these rather sparse databases on climatic change in the following two ways. First, interpolating procedures were used to fit the data points to the six regions of Ontario outlined in Figure 13.2. In Chapter 12, Stewart Cohen provided a capable account of the many problems associated with extending the utility of climatic change data and hence we will not elaborate on these concerns here.

The second transformation involves employing data on monthly norms for temperature and precipitation to estimate a wider range of agroclimatic parameters which influence crop productivity. Figure 13.4 presents the possible effects of each climatic change scenario on growing season length (GSL) in each region of the province. In Northern Ontario, the GSL would be extended to about 150 days under Scenario A, which is similar to the current growing season in South Central Ontario. Northern Ontario's GSL would be even longer under Scenario B, and would approach the current growing season of the present agricultural heartland in South Western Ontario. In South Western Ontario, the growing season would exceed 200 days under both climatic change scenarios and would be similar to the present GSL in southern Illinois. Other growing season parameters investigated in the Ontario study included mean daytime temperature, precipitation, corn heat units and potential evapotranspiration.

Effects on Crop Yields

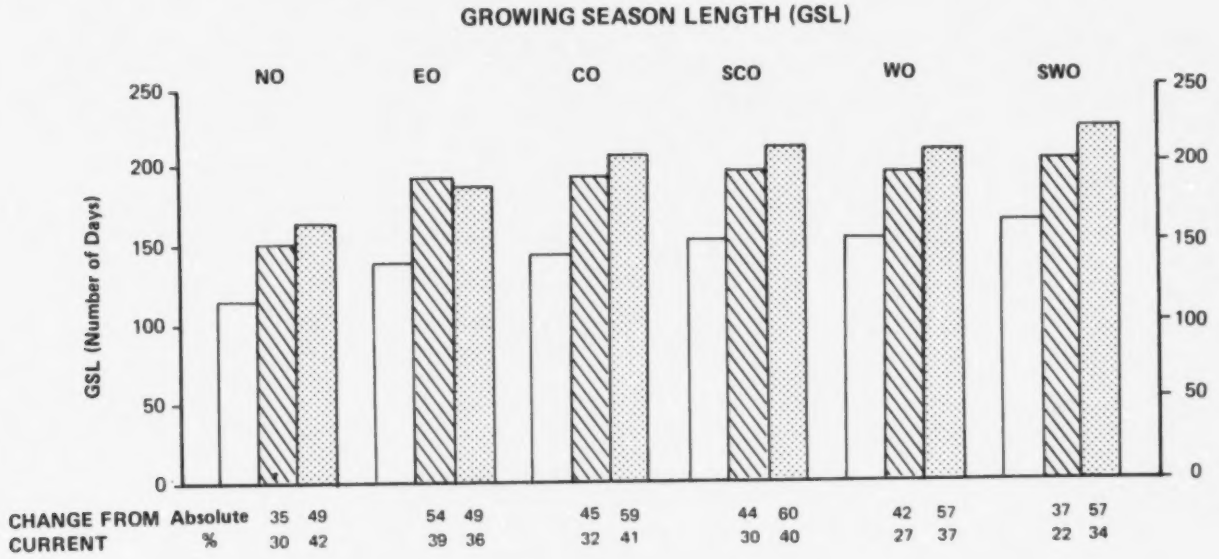
The next step in the assessment provides yield responses to the specified changes in climate for seven major crops in Ontario. The analyses employ a crop productivity model to estimate yield sensitivities to the altered climates. Table 13.2 summarizes yield responses for grain corn. Similar types of analyses are available for fodder corn, barley, oats, wheat, soybeans and hay. A summary of the major findings for all crops follows.

In Northern Ontario, the array of crops that could be grown would be expanded to include grain corn, wheat and soybeans. Furthermore, yield levels for the forages and cereal grains that are currently grown in Northern Ontario would increase substantially under both scenarios for climatic change.

The effects of the changes in agroclimatic conditions in Central and Eastern Ontario would be considerably different than the effects in Northern Ontario. The estimated increases in growing season length and in temperature would enhance conditions for plant growth in these regions, but these benefits would tend to be negated by increases in moisture stress. The negative effects of increases in moisture stress on crop yields would be particularly noticeable on lands with a relatively low drought tolerance. On those lands which have relatively large moisture reserves, yields for most crops would be expected to increase.

In the South Central, Western and South Western Ontario regions, yield levels for most major crops would be expected to

FIGURE 13.4: EFFECTS OF CLIMATIC CHANGE ON GROWING SEASON LENGTH



decline on most land types under both climatic change scenarios. Temperatures would be expected to exceed the optimal levels for crop growth, and moisture stress stemming from increases in potential evapotranspiration would be even more pronounced in these regions. Yields for small grains, oilseeds and potatoes would suffer the most under these conditions. Yields for grain and fodder corn on lands with a low resistance to moisture deficits would be expected to decline, but increases would be feasible on lands with large moisture reserves.

Effects on Agricultural Land Resource Potential

The sensitivity of regional crop production potentials to climatic change is estimated independently for all major crops. Figure 13.5 illustrates the impacts of each climatic change scenario on production prospects for grain corn in each region. These sorts of analyses are also available for fodder corn, barley,

TABLE 13.2: EFFECTS OF CLIMATIC CHANGE ON GRAIN CORN YIELDS

REGION	LAND TYPE	CURRENT FAY[1]	CHANGE IN FAY FROM CURRENT UNDER: SCENARIO A		SCENARIO B	
		t/ha	t/ha	%	t/ha	%
Northern Ontario	A,G	0.0	+ 8.1**	-	+ 9.1**	-
	B	0.0	+ 5.4*	-	+ 6.8**	-
	C	0.0	+ 5.6*	-	+ 7.0**	-
	D	0.0	+ 5.6*	-	+ 5.7*	-
	E	0.0	+ 2.7	-	+ 2.7*	-
Eastern Ontario	A,G	5.4*	+ 2.7**	+ 50.0	+ 3.4**	+ 62.2
	B	3.5	+ 1.4	+ 39.0	+ 1.7	+ 48.0
	C	3.8	+ 1.5*	+ 40.3	+ 1.9*	+ 49.9
	D	3.7	+ 2.9**	+ 79.4	+ 3.6**	+ 98.5
	E	1.8	+ 1.8	+100.5	+ 2.3	+126.8
Central Ontario	A,G	6.6**	+ 1.2**	+ 18.3	+ 1.5**	+ 23.0
	B	4.6	− 0.4	− 9.0	0.0	− 0.2
	C	5.0	− 0.2	− 3.7	+ 0.2*	+ 3.1
	D	4.3	+ 2.9**	+ 66.7	+ 2.9**	+ 66.8
	E	2.0	+ 2.3	+113.3	+ 2.2	+106.8
South Central Ontario	A,G	6.9**	− 0.4**	− 6.4	− 0.2**	− 2.7
	B	4.0	− 1.1	− 26.4	− 0.8	− 19.5
	C	4.1	− 1.0	− 24.7	− 0.7	− 18.0
	D	5.9*	+ 1.1**	+ 17.7	+ 1.0**	+ 17.0
	E	3.4	+ 1.0	+ 27.9	+ 0.9	+ 27.2
Western Ontario	A,G	6.9**	+ 0.1**	+ 1.9	+ 0.2**	+ 2.8
	B	4.1	− 0.6	− 14.6	− 0.5	− 12.7
	C	4.4	− 0.5	− 11.9	− 0.5	− 10.2
	D	5.4*	+ 1.5**	+ 27.0	+ 1.4**	+ 26.4
	E	2.8	+ 1.5	+ 51.2	+ 1.4	+ 50.5
South Western Ontario	A,G	7.3**	− 1.2*	− 16.7	− 1.2*	− 16.9
	B	4.2	− 1.4	− 33.3	− 1.4	− 34.5
	C	4.2	− 1.4	− 33.2	− 1.4	− 34.3
	D	6.4**	+ 0.5**	+ 8.1	+ 0.4**	+ 6.1
	E	3.7	+ 0.6	+ 17.4	+ 0.6	+ 15.3

---

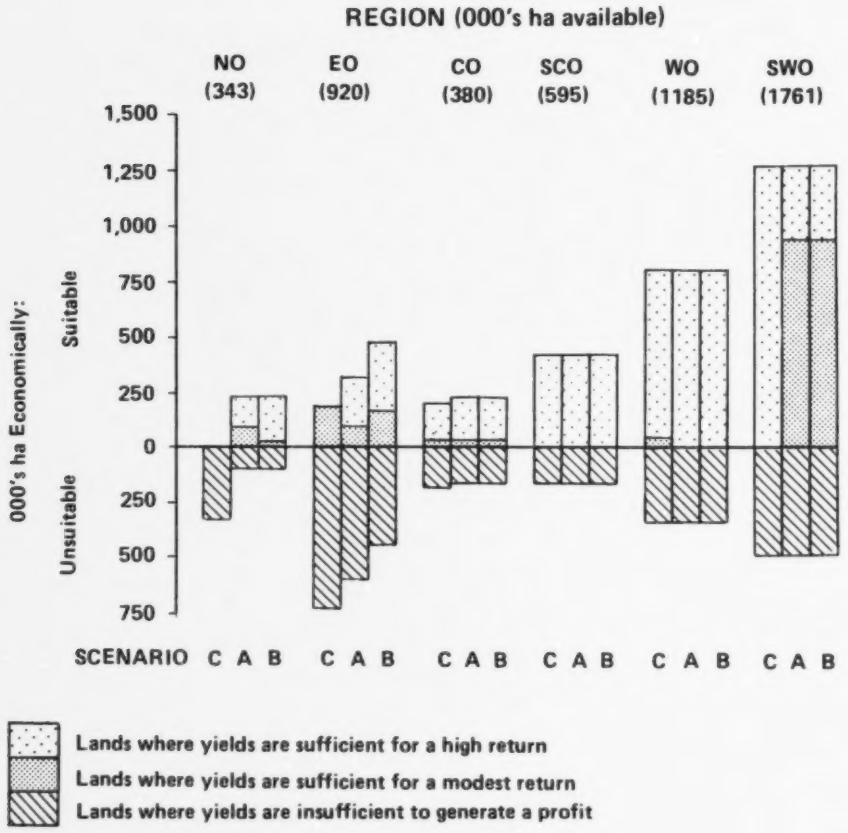
1 Farm Attainable Yields (Dry Weight)

* Yields sufficient for a modest return to investment given current economic conditions

** Yields sufficient for a high return to investment given current economic conditions

No asterisk indicates yields would be insufficient to generate a profit over the long term

FIGURE 13.5: EFFECTS OF CLIMATIC CHANGE ON LAND RESOURCE POTENTIAL FOR GRAIN CORN



Note: Notation for regions and scenarios is defined in Figure 13.4.

oats, wheat, soybeans and hay. The major findings are summarized here.

The area of land with an economic potential for grain corn in the Northern and Eastern Ontario regions would increase considerably under Scenarios A and B. These climatic changes would have only a marginal effect on the economic suitability of lands in the Central, South Central and Western Ontario regions. In the South Western Ontario region, the area of land with an economic potential for grain corn would be unaffected by the specified changes in climate, but there would be less land capable of providing a high return to investment when used for grain corn. The overall effect of the specified changes in climate on the economic opportunities for grain corn would be a modest increase in the total area which would be economically suitable for the crop, but a sharp decline in the area with a high economic potential.

The area of land in Northern Ontario which would be economically suitable for the production of soybeans or wheat would expand considerably under Scenarios A and B. In other regions, particularly Western and South Western Ontario, there would be losses in both the total area with an economic potential for these crops and the area which might provide a high return to investment when used for either of these crops. The economic outlook for the production of soybeans and wheat for Ontario would suffer under the climatic change scenarios.

Losses in economic potential for oats under Scenarios A and B would be confined to Western and South Western Ontario. The economic suitability of lands for oat production in other regions and for barley production in all regions would not be affected by the specified changes in climate.

The economic prospects for fodder corn would be enhanced considerably in the Northern, Eastern and Western Ontario regions. These benefits would however be offset somewhat by lost opportunities elsewhere. Overall, Ontario would experience slight increases in the economic opportunities for fodder corn production under Scenarios A and B.

DISCUSSION AND CONCLUSIONS

This paper demonstrates that models provide a practicable means for bridging the gap between resource inventories and policy issues. The modelling exercise provides a framework for identifying the appropriate data, and for storing the data in a manner which is amenable to subsequent analyses. The models themselves facilitate the analysis of more complex issues regarding the opportunities for land use in a changing environment.

This presentation has provided an overview of the first phase of a broader study investigating the socio-economic implications of climatic change for Ontario. Fully integrated studies of the potential impacts of long-term climatic change on the province's agri-food sector would require additional assessments which would also consider:

1. changes in climatic variability,
2. opportunities for new crops,
3. effects of climatic change on potential food supply, and
4. changes in Ontario's comparative position for agricultural production and trade.

The findings presented in this study are, of course, speculative. Nevertheless, it is reasonable and responsible to draw some preliminary conclusions regarding the policy implications of climatic change for the agri-food sector. Current consensus among climatologists is that a climatic warming of the order specified in this presentation is likely. Such a warming suggests that there might be a shift in those climatic conditions which effectively constrain agriculture. The current constraints imposed by relatively short growing seasons would in all likelihood be replaced by prolonged droughtiness during a lengthy growing season. This, in turn, suggests a redirection for crop research programs. Current efforts to develop crops which mature over shorter periods may be inappropriate given a climatic warming. However, the development of crops which could tolerate drier conditions could alleviate some of the socio-economic consequences stemming from climatic warming in Ontario.

NOTES

1. This section presents highlights from the original study presented in LEG (1985).

ACKNOWLEDGMENTS

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PART 5
USING TEMPORAL AND SPATIAL MODELS FOR NATURAL RESOURCE MANAGEMENT

14

ADEQUACY OF DATA BANKS FOR MANAGEMENT MODELS IN WOOD BUFFALO NATIONAL PARK

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ABSTRACT

This paper provides background on the quality of landscape information available in Canada's national parks but particularly emphasizes Wood Buffalo National Park. At 44,800 km^2, this park is the largest forested national park in the world. Biophysical data banks were developed in the 1970s but these have become outdated and were not readily available to managers in the park. The biophysical information was down-loaded to a microcomputer and now the data can be manipulated by locally available database management systems. The ultimate goal of our study is to utilize land management models to predict long-term changes in vegetation and animal populations and to develop fire management decision support systems which will be useful to park managers. The paper discusses the appropriateness of the available data for these models and emphasizes the necessity of research to establish goals for sections of the landscape so that management programs can be put in place.

INTRODUCTION

Parks Canada is a major land holder in Canada and is a well-established land management agency. It has administered large areas of landscape since Banff National Park was established in 1885. Since then, national parks were added at irregular intervals until the 1970s when large northern parks were established. At present, almost 85,000 km^2 of the boreal forest zone is under the control of Parks Canada. Land acquisition continues with the goal of having representation in all major landscape types in Canada (Lopoukhine, 1983).

When Parks Canada accepted landscapes as national parks the areas were not necessarily in pristine condition. Often the forests were in early stages of succession or under a management system that was quite different from a conservation management strategy. For example, many of the eastern Canadian parks were established in areas of abandoned farmland or clearcut and highgraded forest. As would be expected, there were rapid ecological changes shortly after the new conservation policies were implemented. This has lead to greater awareness of the dynamic nature of the landscape and the need for stronger management programs to prevent losses of the features that are important to a park.

Land management policies have changed over time and as is common with small budgets and a minimal number of personnel, management was largely crisis-oriented and management activities such as fire fighting or insect spraying were often mounted in synchrony

with activities outside of park boundaries. It is only recently that Parks Canada policy recognizes the natural role of disturbance agents such as fire or insect attack in forest dynamics and recognizes the necessity of research to develop sound landscape goals (Parks Canada, 1983). These concerns and future concerns are common to conservation in most countries (Lotan et al., 1985).

The level of biophysical information varies widely from park to park but, in general, there has been an accumulation of data as a result of the long-term interests of wildlife and forestry researchers. The most extensive and systematic inventories of ecosystem characteristics were conducted in the 1970s. These large data banks were to set the stage for more detailed management but unfortunately, for many reasons, including the recent downturn in economic conditions, there has been a delay in the use of this biophysical information. At present most parks personnel are proceeding with a natural resource management process, and a planning process, for each national park. This involves organizing the available information into resource inventories, resource description and analyses, and park conservation plans so that stronger resource management approaches can be put in place. Resource monitoring is to take place over time to ensure that the plans are effective in meeting objectives.

These hardcopy summary reports are an excellent way for new managers to become familiar with the park quickly because information is presented in a digested form; however, it means that the original data are not readily available. To overcome this problem, digital geographic information systems are becoming attractive because they can present large quantities of information in a proper form so that management decisions can be made quickly. These resource management decision support systems have been discussed extensively in this volume. I will mention only that there are several fire management systems being used in the United States, Australia and Canada at the present time (Kessell et al., 1984; Kourtz, 1984).

The objective of our research program in Wood Buffalo National Park is to demonstrate the usefulness of a dynamic geographic information system in reaching some natural resource and fire management goals. The purpose of the present paper is to discuss the strengths and weaknesses of the data now available to successfully meet our objective.

LANDSCAPE UNDER CONSIDERATION (WOOD BUFFALO NATIONAL PARK)

Wood Buffalo National Park is the largest forested national park in the world. At 44,800 km^2 it is larger than the country of Switzerland and six times the size of Prince Edward Island. The park stretches almost 300 km from north to south, reaching $60^{o}32'N$ latitude. The park shares political boundaries with the Province of Alberta and the Northwest Territories and the few roads provide easy access to only a small proportion of the park. Most of the park has undulating relief between 200 m and 300 m of elevation but the Caribou Mountains to the west and the Birch Mountains to the south rise to the maximum elevations of approximately 1,000 m and 800 m, respectively.

Hydrologically, the Peace and the Athabasca Rivers contribute a considerable quantity of water to the Peace-Athabasca Delta which is located at the western end of Lake Athabasca. Water then flows north through the Slave River system, the Mackenzie River system and then drains into the Arctic Ocean. The Peace-Athabasca Delta is probably the largest inland freshwater delta in the world; the hydrological regime of the delta has been modified extensively since the closing of the gates of the W.A.C. Bennett dam on the upper Peace River in 1968.

The vegetation of the park is typical of large areas of taiga (Rowe, 1972). In the northern two-thirds of the park jack pine

(*Pinus banksiana* Lamb.) is found largely on sand dune formations and glacial outwash landscapes which tend to be droughty in summer. On the somewhat finer soils that are less droughty, there is a wide range of mixtures of jack pine, white spruce (*Picea glauca* [Moench] Voss) and trembling aspen (*Populus tremuloides* Michx.). Toward the wetter end of the moisture gradient, black spruce (*Picea mariana* Mill. BSP.) is common, not only on mineral soil but also on organic terrain, which in the northern end of the park, is underlain by discontinuous permafrost. In low lying areas there are extensive areas of black spruce, larch (*Larix laricina* Du Roi K. Koch), alder (*Alnus* spp.) and sedge (*Carex* spp.) communities. In the Peace-Athabasca Delta there are large areas of sedgelands with willow (*Salix* spp.) communities and some trembling aspen and white spruce communities on slightly elevated locations.

The park protects some rare and endangered species; the bison population is now approximately 5,000 individuals; the whooping crane, peregrine falcon, red-sided garter snake, Canadian toad, leopard frog and several bat species have the northernmost boundary of their range within the park. The park is considered by the few visitors to be wilderness but there is some use of the park's resources by native Canadians who are permitted to hunt, trap and fish.

The most widespread disturbance agent in the park is that of fire which periodically modifies vegetation and animal communities. There has been more than 35 years of fire protection effort applied in the park but in the years 1979, 1980 and 1981 the unprecedented low rainfall lead to burning of over 20 per cent of the park; most fires burned through forested landscapes. It is quite easy to recognize that fire management and natural resource management are closely related in these fire prone areas. It is also quite apparent that this is the appropriate time to develop a stronger fire management program because the most hazardous fuels have been reduced over large areas of the park.

SOURCES OF INFORMATION FOR RESEARCHERS AND MANAGERS

Literature, Maps and Photographs

On initiating our project, we found a wide range of qualitative and quantitative information and there were many digests of original data (e.g., Parks Canada, 1984 and 1986). Our initial work brought together a bibliography (Jacobs, 1986) of literature, maps and remote sensing resources to save time for individuals within our team seeking information. Older information was already included in hard-copy bibliographies but we developed a computer database to enable more efficient up-dating and rapid retrieval.

Biophysical Inventory

In the mid-1970s a biophysical inventory of Wood Buffalo National Park was completed on about a scale of 1:250,000 (Airphoto Analysis Associates, 1979). The final reports are available in hard-copy form in libraries and in the form of a digital data bank known as WOODBUFF which is stored at the Canada Land Data System in Ottawa. The data bank is based on northwestern Universal Transverse Mercator units and consists of approximately 1,000 polygons with sub-units. The polygons range widely in size. About 10 are 40,000 ha or larger while well over 50 are less than 50 ha in size. To each of the polygons is attached an attribute file which includes geologic, soil and biological data. It was recognized that WOODBUFF contained a large quantity of data that would be useful to managers in Wood Buffalo National Park if it was more readily available. The data were transferred on magnetic tapes to the University of New Brunswick, and after verification with the associated printed documentation, the data were prepared so they could be accessed through locally available desk-top microcomputers with database management programs (dBASE III

Plus).

The biophysical data are extremely valuable for orientation and to understand the diversities of the park. Even with the microcomputer and suitable database management programs, there are some analytical approaches that can be used by park personnel to answer some management questions. However, a major difficulty with this form of data bank is that it quickly becomes outdated. Although many attributes in WOODBUFF change only slowly over long intervals, some, such as forest type, have changed because of the recent fires. The necessity of more up-to-date vegetation type information for biological and fire behaviour models, quickly suggested the use of more recent remotely sensed data. Satellite imagery and other remotely-sensed data have been studied to verify changes in the data bank and to present information in a more detailed form for input into models. This more detailed information can now be given in pixel size or some composite that is necessary for model input. The biophysical data are most useful at this point as a check against interpretation of earlier satellite imagery during our change-detection analyses. We expect a similar use of the biophysical data for future studies; the biophysical data bank will be a useful starting point but will be superceded quickly by requirements for more spatially-detailed information on more specific topics than that found in the attribute file.

DATA REQUIREMENTS FOR LANDSCAPE MODELS

To operate landscape models in both time and space, a dynamic geographic information system is required. For this, we are utilizing the Computer-Aided Resource Information System (CARIS) which was originally developed for use in both cartographic and resource mapping applications (Jacobs et al., 1988; Masry et al., 1984). CARIS is now linked to a satellite imagery processing system (ARIES II) which enables an economic up-dating of the attribute file (Morin et al., 1986 and 1988) by overlaying the satellite imagery information on the biophysical polygons so that polygon shape and attributes can be modified. Models that predict changes in time and space require the spatial data for initial conditions yet even up-to-date data collected from satellite imagery may not be detailed enough for model input requirements. For instance, available fuel and the vertical distribution of fuel are not directly available from forest cover data but must be interpreted from remote sensed data in a correlative manner after field studies have demonstrated the relationships. Similarly, the biophysical data bank provides useful background for animal population-habitat models but most variables and relationships necessary for landscape models must be developed by further studies.

One of our specific goals is to demonstrate the use of CARIS as a decision support system for day-to-day management of such factors as fire. Weather can be monitored on a daily basis over the season to establish the drought level in the vegetation. When a fire is located, the data bank can be queried for fuel type surrounding that ignition point and then by utilizing ambient temperature, relative humidity, and wind speed and direction, fire behaviour models will predict fire direction and rate of spread (Feunekes and Methven, 1988). If the management goals for the area can be achieved by a fire at this time, and if there are no resources that must be protected, then the fire could be permitted to burn while being closely monitored. If, however, the goal of the area could only be achieved through protection from fires, then the managers can dispatch the appropriate number of personnel and quantity of equipment necessary for the predicted fire behaviour.

In general, only a small proportion of the data now available is directly useful in landscape model construction.

DATA REQUIREMENTS FOR THE ESTABLISHMENT OF LANDSCAPE UNIT GOALS

For any decision support system, it is necessary to have a clearly defined goal for each landscape management unit. These goals may be clearly stated in terms of protecting people, tourist facilities or the threatened habitat of a rare or endangered species. In other cases, the goal may be much more difficult to define; for instance, for larger areas the goal may be to permit fire to play its natural ecological role. In this case, further refinement of the goal will be necessary.

In addition, the goals for contiguous units of landscape are also important in determining a course of action. There may be times when lightning will cause a fire that will play its natural role in a particular land management unit but then may go on to wreck havoc (as judged by a stated goal) in surrounding land management units.

The development of goals can be a subjective process conducted by individuals who have experience with similar problems elsewhere or who have considered the particular problem for many years. In other cases, the goal is developed through compromise and consensus by a number of individuals who have different experiences, interests, and opinions. These decisions are based on the pool of information available at that point in time.

A decision to let areas burn after lightning strikes brings the land manager under pressure to provide quantitative information well ahead of time to justify the decision. Specific data can be collected if the requirement can be clearly formulated. Small scale experiments may be suggested although in the past Parks Canada has encouraged survey methodology over experimental manipulation. Many problems of time and space faced by park managers cannot be approached experimentally so an investigation through ecological models is a useful approach. As indicated earlier, initializing data will be available but relationships or process-oriented information is probably not available. This information must be collected for the specific task. For instance, in developing a forest growth model or a fuel production model, the growth relationships between yearly air temperatures and species probably must be collected (El-Bayoumi et al., 1984; Wein and El-Bayoumi, 1988).

One further problem must be overcome before a model is useful in establishing goals. The model must truly capture the dynamics of the system; the model must be realistic. One of the major difficulties with landscape models which operate in time and space is that most available data are used to build the model and few data are then available to determine if model output is reasonable. A major strength of Parks Canada is that data have been collected for many years and these data are often gathered in a systematic manner to provide long-term records of, for example, animal population changes. Unfortunately, long-term data are collected on only a few topics. All too often, it is still necessary to evaluate model output through the experience of individuals who have been familiar with the park for a considerable period of time.

If the dynamics of the system can be captured in a modelling exercise, a range of management strategies can be simulated by the model. For instance, the model could be run for fire frequencies with a probability of 0, 1, 2, 3 or 4 fires per century. The model outputs for each strategy could be compared to determine which fire regime suggests the goal for that particular landscape unit. Similarly, if animal population dynamics are related to habitat, the same type of management strategies could be evaluated to determine which scenario will lead to the appropriate animal population level.

CONCLUSIONS

Although many person-years have been spent in collecting various types and qualities of data, and much effort was spent in collecting data for the biophysical survey, data are not adequate for most landscape models. Data for present and future modelling exercises must be collected by present and future researchers. Data such as those in the biophysical data bank are useful for perspective, but more importantly, they are essential for verification of model output. Modelling exercises usually will require subjective decisions and usually will rely on the experience of park personnel. These concerns should not be interpreted as criticism of past or present data collectors or park personnel; these are the inherent difficulties in utilizing spatial and temporal landscape models to answer specific questions.

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15

USING CARIS AS A TOOL IN NATURAL RESOURCE AND FIRE MANAGEMENT MODELS

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ABSTRACT

A geographic information system (GIS) provides a natural resource manager with a means of quickly cross-referencing graphical land information with associated textual data. The Fire Science Centre has obtained the Computer-Aided Resource Information System (CARIS) GIS to be used in the development of a dynamic resource management system, particularly for fire management, for Wood Buffalo National Park. This system will incorporate the GIS capabilities of CARIS with remote sensing to keep the graphical and textual data current and with biological models that will aid in forecasting. A description of CARIS and how it is used within this project is given.

INTRODUCTION

The management of land resources has been an on-going process dating back to Mesopotamia where agricultural resources were mapped and recorded. Over time, though the technology has changed, managers of land resources are maintaining similar systems; that is a graphical representation, usually in the form of a series of maps, and an attribute system, consisting of a series of tables.

With the introduction of computers we have seen in many cases the manual system being replaced by a digital system. The computer has now given the land manager three options. Pure graphical and textual systems are still in wide use. The third is a working combination of these two and is commonly referred to as a geographic information system (GIS).

Classical large geographic information systems include the Canadian Geographic Information System (CGIS) of the Canada Land Data System (CLDS) and ARC/INFO. The newest systems are small enough to run on a micro-computer such as the Spatial Analysis System by Tydac Technologies Inc. (1986).

Geographic information systems have given the land manager a means of quickly cross-referencing graphical information with associated textual data. By working between the two data sources a land manager can quickly obtain the present characteristics of a tract of land. For example, one may inquire about the location of mature spruce within a predefined area. The inquiry would be made through an attribute inquiry and the resulting graphical information could then be displayed on the graphics screen. Once this information is displayed it may be refined by locating bounding lakes and rivers, roads,

soil characteristics, etc. The objective is to obtain a graphical and textual report based on specific parameters.

Another example would be graphically defining an area and obtaining an input data file for a modelling algorithm. Results of this algorithm may then be reconstructed graphically and superimposed on the original graphical data.

The Fire Science Centre of the University of New Brunswick acquired the Computer-Aided Resource Information System (CARIS) GIS, developed by Universal Systems Ltd. of Fredericton, New Brunswick (Masry et al., 1984) to conduct research on a resource management system, especially fire management, for Wood Buffalo National Park. This paper will describe CARIS and discuss its use as a tool in natural resource and fire management models.

CARIS

Description

The design of CARIS is based on concepts similar to those which have been in use in some digital mapping systems in Canada for a number of years. These include the CGIS which deals mainly with polygonal maps, and the Canadian Hydrographic Service System which deals with cartographic production of charts. CARIS began receiving public attention in 1983 when the Canadian Maritime Provinces Land Registration and Information Service (LRIS) acquired the system for topographic mapping. The LRIS was searching for a system that could handle its topographic needs and would later be applied to its topological needs (i.e., cadastral mapping).

The evolution of CARIS is based on the study of data structures, an important element in an effective GIS. CARIS employs a data structure which is both powerful and efficient in meeting the needs of geographic information users. These needs include handling both topographical mapping data (point and line based) and polygonal maps with their topological relationships (area based data). The data structure is based on the vector storage format. The result is a system that has the following characteristics (Figure 15.1).

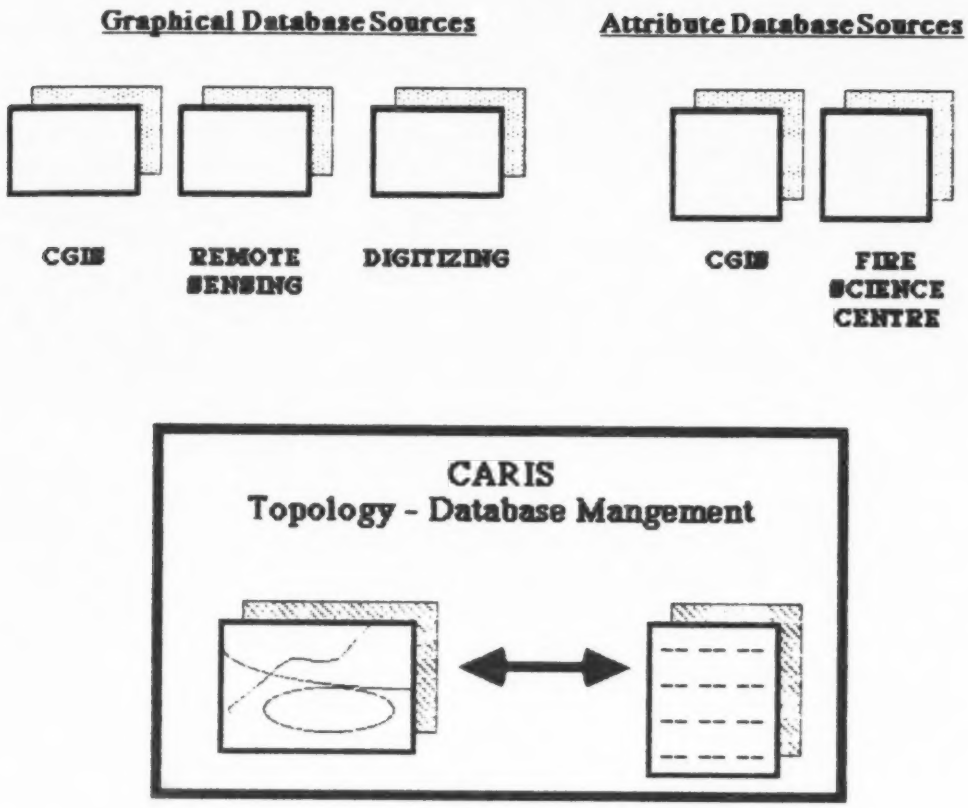
1. It allows data to be imported from a variety of data sources, such as photogrammetry, digitizing tables, remote sensing, electronic field surveys, and other databases.
2. It allows a variety of internal applications necessary for efficient database processing and maintenance. Some of these applications consist of:
   a. the ability to support full topology. These data consist of points (i.e., key elevations, sensor locations, symbols, etc.), lines and/or polygons -- each with their associated attributes,
   b. the rapid retrieval of information regardless of the size of the database, and
   c. the ability to incorporate, identify and process data from a variety of sources at desired scales and projections.
3. It allows for the export of data to a variety of targets, such as plotters, other databases, other information systems, and/or modelling algorithms.

The system installed for the LRIS in Summerside, Prince Edward Island consisted of seven independent workstations based on DEC PDP minicomputers. Since 1983 CARIS has utilized DEC's VAX family of minicomputers and has taken full advantage of the 32 bit architecture of these computers.

With the transfer of CARIS to the VAX, the software has consolidated into a number of software modules.

1. Primary Graphics which allow the user to compile, maintain and process geographical data, and Extended Graphics used to incorporate this data into a topological database,
2. Topology-Creation which is used to process and maintain network and polygon

FIGURE 15.1: CARIS DATA STRUCTURE



databases,
3. Topology-Database Management which allows the user to interact with both the graphical and attribute databases,
4. Topology-Continuous Database Management which allows the user to create an indexed topological database that extends beyond the limits of a single file, and
5. Database Management Interface which involves a series of utilities which allow a user to access the database management system through a CARIS interface in order to improve attribute database inquiries and modification of attribute fields.

One of the major features of the Topology-Database Management module is its ability to perform layer analysis. This allows the user to group common graphical features into a number of dynamic layers based on feature codes and other CARIS identifiers. By referring to the layer number, either by keying it in or through the use of macros, the user may suppress or display that layer instantly. This feature is particularly useful to view historical data. For example, forest stands before a fire or the path of the fire movement across the landscape at regular time intervals.

The CARIS modules listed above also have a number of unbundled sub-systems. Some of these are listed below.

1. Overlaying allows the user to combine layers of information to produce an additional layer. This additional layer maintains the integrity of previous layers but also provides the user with the ability to query about overlaid characteristics. For example, by overlaying a forest layer with a soil layer a user may obtain the locations of black spruce where the soil material is classified as glacial till,
2. Corridor Analysis allows the user to restrict all inquiries to the information contained within a user-defined corridor. This is attractive for modelling since an algorithm can define the corridor of interest.
3. Shading is a minor sub-system used to highlight closed areas or polygons for plotting. The graphics terminal has its own shading facility for digital data.

Applications

CARIS has been applied to a number of geographically-based disciplines, both nationally and internationally. Some examples of these applications follow.

1. Hydrographic chart production for the Canadian Hydrographic Service and the Royal Netherlands Navy.
2. Topographic map production for the Canadian Maritime Provinces, through the LRIS. Topographic and thematic maps are also produced by a service bureau in Australia.
3. The development and maintenance of an urban infrastructure information system for the City of Halifax. Data will consist of:
   a. digital topographic mapping compiled by the LRIS,
   b. water and sewer information compiled from existing plans by a local service bureau; the Eastcan Group of Survey Consultants, and
   c. property information compiled by a provincial service bureau; the Maritime Resource Management Service (MRMS).
4. Environmental studies for the Canadian Department of Fisheries and Oceans, Fish Habitat Division.
5. Agriculture land-management studies for the New Brunswick Department of Agriculture.
6. Geo-science studies for the New Brunswick Department of Natural Resources - Geology.

CARIS is also being applied to a number of research fields, such as those which follow.

1. The development of an electronic chart for ship navigation. This chart incorporates CARIS with a ship's sensors

and positioning systems.
2. The development of a three-dimensional GIS utilizing octrees. This sub-system of CARIS has applications in geo-science, facility management, and volume modelling, for example.
3. Natural resource and fire management models (as in the study being conducted in Wood Buffalo National Park).

METHODS

The Application of CARIS to Wood Buffalo National Park

Background Preparation

Fire Science Centre researchers wish to demonstrate the use of a dynamic GIS for Wood Buffalo National Park primarily using the CARIS software to interact with remote sensing methodologies and ecological models. The main purpose of this study is to provide park management with rapid access to current park information to aid in efficient resource and fire management.

The CARIS system has been installed on the Fire Science Centre's DEC MicroVAX II computer which is equipped with two 71 MB hard disks, a 9 track tape drive and a 91 MB tape cartridge system. This super micro facility has connections for up to 8 terminals. The Centre also has access to a CARIS workstation consisting of a Tektronix 4115 colour graphics terminal and a 36 in (91.4 cm) x 48 in (121.9 cm) digitizing table with micro-based controller, a DIPIX ARIES II satellite imagery system and a printer; all located in the Digital Mapping Lab of the Department of Survey Engineering.

A biophysical inventory of Wood Buffalo National Park, completed in 1977 (Airphoto Analysis Associates, 1979), was obtained from the CGIS of the Lands Directorate in Ottawa. This information is in two forms. The first is a series of digitized coordinates for over 6,000 arcs (lines). Coordinates were given in Universal Transverse Mercator (UTM) units specified as northing and easting values. The arcs interconnect to form a map of 1,031 closed areas called polygons which represent the different biophysical units in the park. The second is a biophysical classification describing each of the polygons using over 100 attribute categories. Examples of the attributes include area, elevation, land district, geological formation, soil and geology characteristics, and vegetation composition.

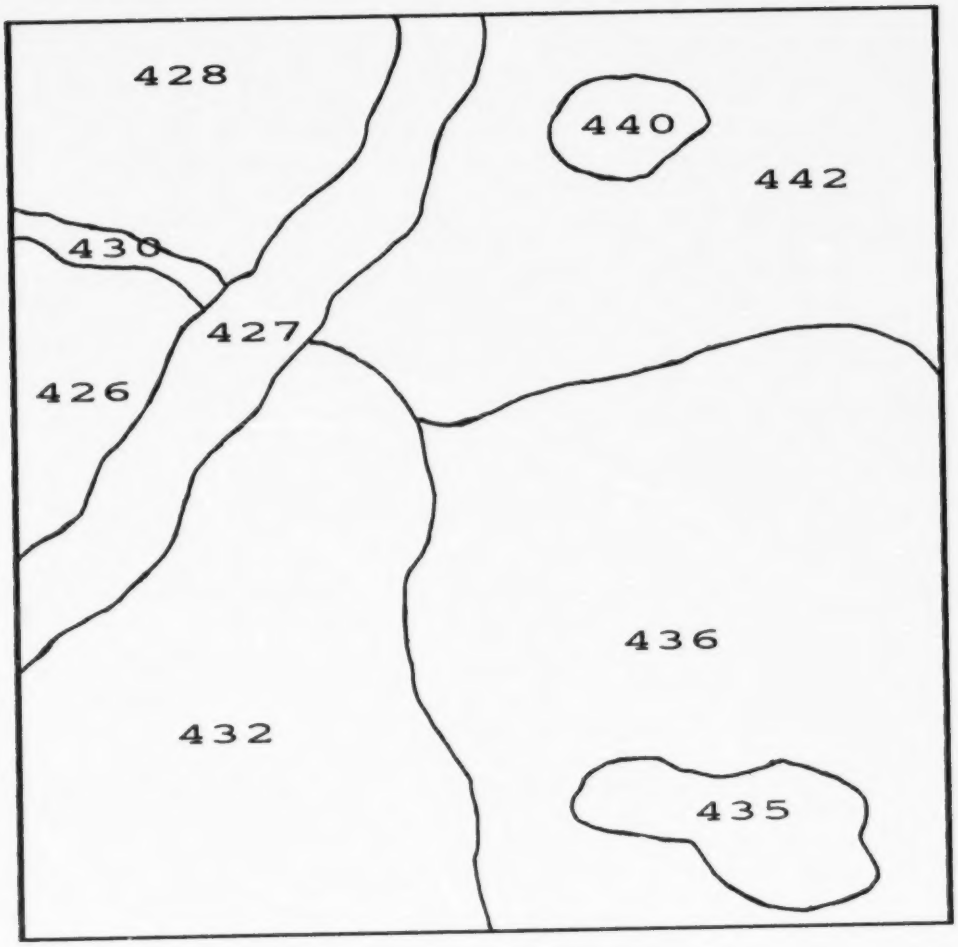
The CGIS files for the park, received on tape, were transferred to the IBM mainframe computer at the University of New Brunswick. A simple record format had been used to store the information but many clean-up operations were required to make it usable. The data files were then converted to DLG, a popular data transfer format, and transported to the MicroVAX II. Here, the files were written to CARIS interchange (NTX) format.

Developing the Database in CARIS

CARIS graphics files were set up from the NTX file of digitized arc coordinates. Using these files, a map of the park could be displayed with the Tektronix graphics terminal (Figure 15.2). The polygon numbers were added to the graphics in the form of labels and placed at the geometric centre of the polygons. These numbers and their graphical locations were obtained from the attribute data. It should be noted that due to the nature of CGIS data the geometric centre of a polygon is not always inside the polygon boundary; thus, some of the numbers had to be moved.

CARIS procedures were used to produce the network formed by the arcs. From this, a polygon file was created which indexed the closed areas formed by the network. To complete this process, the CARIS editing features were used to identify, locate, and correct errors affecting the topology. This included digitizing errors (i.e., sections of arcs digitized twice and dangling arcs) as well as polygon numbers located outside proper boundaries. The polygon labels were set up as the graphic indexes to the polygons.

FIGURE 15.2: PARTIAL MAP[1]



[1] Includes polygon labels as they would be displayed using CARIS with a graphics terminal.

Once the topology was built, the attribute data were added to the relational database management system used with CARIS. These data were then linked to the polygon graphics files using the polygon numbers as indices. Some analysis will be done to investigate the attributes currently used and to determine what should be changed and added.

With the topology and database management modules in place, the graphics display can be used to select polygons in order to gain information about them and it can also be used to highlight or shade polygons which have attributes in common. This ability to reference area data quickly is very useful for immediate management decisions. A user

will also be able to take full advantage of the more advanced features of CARIS such as overlaying and corridor analysis.

The entire procedure of setting up the park database from the CGIS data took approximately three weeks. This does not include the time taken to develop the procedures used. Polygon building with error correction used a major portion of this time due to the large number of arcs and polygons involved. Cleaning up the original data also took significant time.

Integrating CARIS with Remote Sensing and Modelling

One of the objectives of this study is to link the DIPIX ARIES II satellite imagery system at the University of New Brunswick with the CARIS (Morin et al., 1988). This will allow the use of remote sensing to aid in updating the park vegetation database. This is especially important with large areas the size of Wood Buffalo National Park. Software has been developed to convert a satellite image in its raster format to the interchange (vector) format of the CARIS software and vice versa.

As remotely-sensed data become available, they will be classified using techniques which have been developed for the park characteristics. These classified images will be converted to CARIS interchange files and subsequently to graphics files. These new data will be stored as a different graphical layer from the current database so as to keep an historical record. Layer analysis will be applied to determine where and what changes have occurred and the attribute data can be updated accordingly.

A second objective of the study is to provide an aid to short and long-term park management by integrating models with the GIS. The CARIS database will be used as input to a forest succession model described in El-Bayoumi et al. (1984) and Wein and El-Bayoumi (1988) (Chapter 17) and the fuel and fire spread model described in Feunekes and Methven (1988) (Chapter 18). A new graphical layer can be created from the model output and used with overlay processing and analysis to give a manager a graphical picture of changes which might take place in a given area when certain conditions are applied.

The forest succession model has been transported to the MicroVAX II environment from the IBM mainframe. Some minor code adjustment was required. Work is currently being done in interfacing the CARIS database with the input requirements for this model.

With database expansion, any number of modelling applications could be incorporated with this system (Wein and El-Bayoumi, 1988) (Chapter 17).

Training And Technical Support

The design of CARIS reflects the operating system used to drive the software. This means that the user who is familiar with the operating characteristics of VAX/VMS would be on common ground with CARIS. This feature also helps reduce the training time for a new operator.

Training for a new CARIS operator generally involves two weeks for primary graphics and two weeks for topology. During this time the operator is made aware of features, such as on-line help, command structures and the use of menus and macros designed to make using CARIS easier. Further training with respect to the Wood Buffalo National Park data can be gained through experience. Additional time would be required to become familiar with the ARIES II system.

Data Transfer To Personal Computers

One of the most discussed topics has been the ability to transfer data between a GIS, such as CARIS, and small microcomputers. One should be aware that the size of the database and the number of data processing operations does restrict itself to a larger system like that of a MicroVAX II. However, attribute data may easily be transferred between systems by writing out an ASCII

file of attribute information, transferring it to the required system and using a bulk loader to place the data into a database management system. This is a two-way operation.

There is also the possibility of utilizing a microcomputer as a graphics terminal using software packages like Tekalike. Although the user cannot add information with this software, a graphics picture may be downloaded to the micro and plotted locally to support an operation.

ACKNOWLEDGMENTS

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16

UP-DATING LANDSCAPE DATA FOR NATURAL RESOURCE MANAGEMENT THROUGH LANDSAT IMAGERY

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ABSTRACT

There was a favourable comparison between automated image analysis techniques using Landsat (MSS) imagery and more traditional sources of remotely-sensed data for northern forest species and cover types. Results also indicated that valuable information concerning vegetative regeneration after fire was available from Landsat (MSS) data. Insights gained from this analysis suggested that despite coarse levels of spatial resolution which have limited its effectiveness in southern forest areas, Landsat (MSS) is useful in developing and updating inventories for northern forests. This is due to the fact that cyclic coverage by satellites often provides the only up-to-date information available. Low tree diversity of the northern forest canopy permits higher accuracy levels at lower levels of resolution. Comparable levels of discrimination are also achieved because most existing inventories for northern areas are at medium to small scale.

INTRODUCTION

Many attempts have been made to utilize Landsat (MSS) information as a tool in forest management since the launching of the satellite in 1971. Some researchers have focussed on applications of the optical image products from Landsat (Hall et al., 1983; Pomeroy, 1985) while others have focussed on the development of digitally-based analysis and classification procedures. Harvey et al., (1982) provided a discussion of digital classification procedures as applied to northern cover types. A further discussion of digital analysis procedures is provided by Kalensky et al., (1981) who tested supervised and unsupervised procedures within the boreal forest region of northern Saskatchewan.

Flexibility and sophistication in handling of satellite data has been improved in recent years due to the development of specialized digital enhancement procedures. Many of these approaches utilize the computational efficiency of the computer, while retaining the flexibility and experience provided by a human operator. This type of approach was utilized by Beaubien (1983) to map forest areas of Quebec. Applications and interpretations of digitally enhanced imagery for Canadian forest zones are outlined in Ahern and Bennett (1985). This development and testing of procedures over the last 10 to 15 years seems to have resulted in a consensus that Landsat (MSS) is capable of defining hardwood-mixedwood-softwood level forest categories with accuracies of 70-90 per cent (Kalensky et al., 1981).

Increased levels of spatial resolution offered by newer sensors, such as Landsat Thematic Mapper (TM) or the French Spot satellite

should significantly increase presently available accuracy levels. Research testing the application of Landsat TM data to Canadian forestry problems is currently under way (Ahern and Archibald, 1986).

Many researchers feel, however, that even with the resolution levels afforded by newer systems, there is still insufficient discrimination of ground features, and cover types, to permit formulation of operational inventories using Landsat data alone (Ahern and Archibald, 1986). In areas north of the commercial zone, however, where management requirements are not so stringent, it is conceded that resolution levels may be sufficient to establish useful inventories (Ahern and Archibald, 1986).

The objective of this work was to utilize Landsat (MSS) data for a portion of Wood Buffalo National Park to identify major vegetation types. This information is required as a basis for developing fuel maps and animal habitat maps.

METHODS

Study Area

The research was carried out in Wood Buffalo National Park which at 44,800 km^2 is the largest National Park in North America. Since the most hazardous forest fuels were located in the northern part of the park, a 30 km x 30 km study area was centred around Angus Tower. This area contains a variety of vegetation types ranging from jack pine (*Pinus banksiana* Lamb.) on the driest sand dune areas, through mixtures of jack pine, white spruce (*Picea glauca* [Moench], Voss) and trembling aspen (*Populus tremuloides* Michx.). In the wettest forest types, black spruce (*Picea mariana* Mill. BSP.) and larch (*Larix laricina* Du Roi K. Koch) dominate.

Extensive changes to the forest stand types and ages have resulted from fires that burned as much as 50 per cent of the study area within the last 30-40 years.

Classification Procedures

Comparison of digital and non-digital classifications was facilitated by registering the July 1984 Landsat (MSS) image used to Universal Transverse Mercator (UTM) map coordinates. Digital analysis involved the use of a supervised parallelepiped classifier. It was discovered that increased accuracy and discrimination levels could be achieved if the image to be classified was first enhanced using a principal component transformation. All operations on digital data were carried out using a DIPIX ARIES II image analysis system and associated software.

The non-digital classification was compiled using traditional data sources, such as aerial photography and ground surveys. Such data sources were known and tested, and more importantly were accepted for operational use. It is for this reason that this classification was accepted as a reference or bench mark against which classifications based on digital data could be compared.

Information from initial ground truthing activities conducted during the summer of 1985 was included within the reference classification. By overlaying a common grid over reference and later digital classifications, identical ground points could be selected for comparison. Using this method, a total of 930 common points were selected and compared. By noting the category into which each point was assigned, on reference or digital classifications, a measure of the similarity of the various classifications was established.

One variable which has had a major influence on the vegetation is fire. Major fires in 1979, 1980 and 1981 affected a large portion of the study area. It was apparent that data concerning regeneration was being provided by Landsat (MSS) but the accuracy of this information could not be assessed due to the fact that reference data, such as air photography, had been collected prior to the fires. To overcome these problems, a second series of ground surveys was undertaken in

the summer of 1986 and particular attention was paid to the stages of vegetation development after fire.

RESULTS

Jack pine dominated stands covered about 40 per cent of the study area. These even-aged stands, established after wildfires, were well separated from other species. It was found that selective use of enhancement and training procedures resulted in discrimination of two distinct age classes of jack pine. The first consisted of jack pine aged less than 30 to 35 years, while the second group comprised older stands aged from 35 to 120 years.

Aspen was the major deciduous tree species in the study area. With an overall classification accuracy of 88 per cent this class was also well separated from other species. These stands were much smaller and more heterogeneous than the jack pine stands. This made it difficult to establish effective training areas for subdividing this class. Largely because of this fact aspen stands could not be categorized according to age. Similarly mixed aspen stands containing a significant component of jack pine or spruce could not be separated.

Stands of willow (*Salix* spp.) and alder (*Alnus* spp.) occurring along edges of water bodies or meadows were discriminated with an accuracy approaching 98 per cent. Due to the fact that these species occurred in close association with sedges or grasses, it was difficult to assess the extent to which each was contributing to the overall spectral response. The small size of these stands also contributed to difficulties in subdividing this category.

Two bog and fen categories were separated. The first type consisted of areas blanketed by a layer of sphagnum peat. Underlying permafrost in these areas had pushed the ground into a series of irregular raised polygons or palsas. These palsas provided the distinct pattern which made this bog type readily visible on both photographic and digital imagery. Vegetation consisted largely of stunted black spruce and shrubby vegetation such as Labrador tea (*Ledum groenlandicum* Oeder). Sedges and lichen colonies were also common.

The remaining bog and fen types were grouped together because they could not be separated easily. A major constituent of this group included fen areas dominated by vegetation such as Labrador tea and dwarf birch (*Betula glandulosa* Michx.). Other bog areas tended to have higher water tables. In these areas, vegetation graded from dwarf birch and Labrador tea to sedges in the wettest zone. Stunted and scattered stands of black spruce and larch also occurred. Environmental conditions such as frost action and differing water regimes produced characteristic reticulate or dermatoid patterns (Muskeg Research Institute, 1971).

The major reason these areas were not well separated was that although relative densities and distributions of plant species could vary within a particular bog or fen, similar species tended to reoccur across bog types. These varying distributions of plant species resulted in distinct patterns visible on both satellite and aerial imagery. Despite this, there was significant overlap in the spectral response from different bog areas on digital imagery.

There was also some overlap between palsa bogs and the second bog category; however, palsa bogs could be separated due to extensive lichen colonies that occurred on most palsas.

Black spruce and larch stands could not be separated into distinct categories because these species formed scattered stands in bog areas. Tree crowns generally covered less than 20 per cent of the ground area so this open configuration meant that the spectral response detected by orbital sensors emanated primarily from understory vegetation. Due to the fact that this understory tended to be Labrador tea or dwarf birch, such areas were

again confused with other bog categories.

Upland black spruce stands within the study area were small and could not be separated from surrounding tree species.

Areas of open water, such as lakes, rivers and large ponds, were easily established as a separate class.

The 1986 surveys confirmed that differential effects of wildfires, as viewed from Landsat (MSS), could be grouped into three categories. The first category related to areas only mildly affected by fire where canopy vegetation had largely survived and understory vegetation had re-established quickly. In more severely affected areas, vegetation had been killed but five years after the fire, vegetation was re-established. The most severely affected areas were those in which fire had removed not only the vegetation but also the underlying layer of organic soil. In these areas there was limited vegetation and wide areas of mineral soil still exposed.

DISCUSSION

The cyclic coverage provided by Landsat can be a critical factor in updating inventories for northern areas. The time and expense necessary to update traditional aerial imagery make short update cycles prohibitively expensive, leading to extended or irregular cycles for many northern areas. Within the boreal forest this problem is compounded because wildfire can quickly render imagery for large areas obsolete. In the ten years since photographic coverage was last acquired for this study area extensive wildfires have created large areas for which the only current and economic source of data is that from Landsat.

Although the potential resolution of inventories compiled from aerial photography is theoretically unlimited, most commonly available vegetation inventories for northern areas have been compiled at medium or small scales. This has occurred because the large areas involved and the less intensive use of forest resources must be balanced against the increased costs of large-scale inventories. As a result, levels of detail provided by orbital sensors, such as Landsat, may approach or even exceed those of currently available inventories. In this study it was found that Landsat (MSS) data easily supported mapping scales of 1:100,000. This compares with mapping scales of 1:250,000 used for existing inventories.

Relatively high accuracy levels were also facilitated, despite the coarse resolution levels of Landsat (MSS), because the boreal canopy tends to be less complex than forest covers in southern areas. Individual stands are larger and generally contain fewer dominant species; five species occupied over 90 per cent of the study area under discussion.

A review of presently available techniques for automated digital analysis indicates that these rely on intensity differences between individual pixel units within the scene. Information from recurring patterns between groups of pixels cannot be utilized. It was pointed out earlier that the response of vegetation to environmental conditions provided visual patterns characteristic of specific bog and fen types. These patterns were visible on both photographic and digital imagery, but the species comprising these patterns and hence the spectral response from them were similar across bog and fen categories. This meant that such patterns were, for purposes of computer analysis, indistinguishable and some categories were generalized into broader classes. Even though this class structure was less than optimum for operations such as fuel modelling or for fire mapping, it had to be accepted. Presently available systems and procedures for analyzing digital data may limit the range of results available to users or dictate that they be structured somewhat differently than those from traditional sources. It is apparent that many potential users do not realize that such differences can occur and are in many cases unavoidable.

More sophisticated analysis of satellite data is possible and should be investigated to

utilize this data source more fully. This includes investigations of multidate image analysis techniques as a means of determining the extent to which fire-related vegetation changes and subsequent regeneration levels are detectable. Methods of analyzing textural patterns visible on Landsat imagery should also be tested. These may permit definition of additional age classes within deciduous and coniferous stands and may permit a more complete separation of bog and fen categories.

A major opportunity to strengthen digital analysis methods has arisen from the development of software links between image analysis systems such as the DIPIX ARIES II and digital geographic information systems. The existence of such links not only facilitates direct updating of digital data banks using satellite data but also facilitates the integration of data residing within geographic information systems during image analysis procedures. Information such as topographic data or contextual information can now be conveniently utilized in fuel mapping (Burgen and Shasby, 1984).

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17

POTENTIALS OF LONG-TERM TEMPORAL AND SPATIAL VEGETATION MODELS IN PARKS MANAGEMENT

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ABSTRACT

Mathematical models are useful to understand the dynamics of vegetation in that these approaches efficiently point out information that is missing and also enable extrapolation of data points in relationships. Vegetation models are being used in Wood Buffalo National Park to explore forest dynamics over time and also to explore animal habitat changes over time. A forest stand model, based on the FORET model, has been adapted to the northern portion of the park to capture the dynamics of the system and is now being used to predict vegetation composition under a range of fire frequencies, intensities and severities. The model is primarily temporal in nature but is being linked to spatial data banks in order to obtain a better understanding of changes in time and space. The model will be useful in exploring the movement of ecotones between vegetation types under different fire regimes or in exploring changes in vegetation caused by long-term climatic shifts. The paper also points out the requirement for other types of models such as one that mimics the fuel production and habitat changes in sedge and grassland meadows that are common in the Peace-Athabasca Delta, which is located in the southern portion of the park.

INTRODUCTION

One of the developments in the field of vegetation dynamics in recent decades is the increasing use of mathematical models in many research aspects (e.g., West et al., 1981). These approaches have been useful in synthesizing available knowledge and therefore identifying missing information. While recognizing the complexity of ecosystem dynamics, it is interesting to note that even simple models have been useful because they can capture a large proportion of the variability and responsiveness of forests. The models can therefore be used to guide both short and long-term experimentation by raising useful hypotheses to be tested and by exploring alternate management strategies to suggest the best choice of the strategies to reach a particular goal. Modelling exercises do not replace experimentation which remains the basic approach to the scientific method.

The literature contains a wide range of forest growth models that vary in terms of time scale and complexity (Dudek and Ek, 1980; Shugart and West, 1980). In general, the less complex the model, the easier it becomes experimentally to test the hypotheses raised. Most models have been developed or adapted to commercial forests; only a few

models (e.g., Yarie, 1986) are available for the northern coniferous forests. In this northern coniferous zone or taiga the two main disturbance agents that periodically influence forest ecosystems are insect attack and fire. Insect attack has received considerable attention in the literature particularly in eastern Canada (Cuff and Baskerville, 1983; MacLean, 1981). Post-fire succession studies in northern forests have also received a good deal of attention and a number of papers have attempted to synthesize the field of fire ecology (see review papers in Wein and MacLean [1983]). Much of the information available on these disturbance agents has been gathered through survey and experimental approaches although in more recent years there are some attempts at modelling (Kimmins and Scoullar, 1979; Yarie, 1986).

Almost all of the above disturbance studies consider the temporal dimension of vegetation dynamics; few examine the interactions between spatial and the temporal dimensions. This is important to note because forest succession or forest composition change can be confounded by the spatial dimension, especially if the severity of the disturbance is spatially specific. For instance, certain areas of the landscape, including aquatic systems or moist vegetation types, will act as barriers to the spread of fire. In addition, within a given disturbance there will be ranges of disturbance intensity depending on the landscape type or the location on the landscape. For example, in years when considerable moisture occurs early in the season, fires may burn only through the driest portions of the landscape during the summer; yet, in years of low rainfall, fires may burn throughout the landscape and completely remove soil organic matter that has accumulated for centuries.

The objectives of this paper are to describe models being used to understand the long-term dynamics of post-fire vegetation. The paper also describes the longer-term objective of the research which is to develop alternate management strategies of reaching goals. This is to be done by predicting the long-term changes in vegetation under a range of fire regimes (frequencies, intensities and severities) that might be implemented as management strategies to reach particular goals.

METHODS

Study Area

Wood Buffalo National Park, at 44,800 km^2, is a large area but its vegetation types are quite simple when compared to temperate regions. We have chosen to look at the dynamics of the two major vegetation types. Approximately two-thirds to three-quarters of Wood Buffalo National Park is forested with pure and mixed stands of jack pine (*Pinus banksiana* Lamb.), white spruce (*Picea glauca* [Moench], Voss), trembling aspen (*Populus tremuloides* Michx.), black spruce (*Picea mariana* Mill. BSP.), and larch (*Larix laricina* Du Roi K. Koch). The remaining area is dominated by sedgelands exemplified by the wetland meadows in the Peace-Athabasca Delta.

Forest Dynamics Model

To date the work has largely focussed on forest gap phase models that have been described by Shugart (1984), and more specifically for the present study, by El-Bayoumi et al. (1984). The reader is directed to these sources for details of model construction. The more recent model BURN is based on earlier models which simulate the establishment, growth and mortality of individual trees in a stand over decades and centuries. BURN begins the simulation with tree species seeds establishing stochastically on bare soil or it introduces new trees as a result of stump sprouting. The model calculates annual growth increment for individual trees as a function of climatic conditions and competition for light and space and removes trees due to age, changing environmental conditions or due to disturbance agents that cause reduced growth or death.

In adapting the model to Wood Buffalo National Park it was necessary to calibrate the model to the growth conditions and

species found in the general area. To verify the simulation output, independent data were gathered on diameter-height-age relationships for species over a wide range of the park. Climatic parameters were also identified using local meteorological records.

Meadow Vegetation Dynamics Model

The construction of this model is being initiated because large areas of wetland meadows are primary grazing habitat for bison populations, and in addition the vegetation dynamics of the Peace-Athabasca Delta has been strongly influenced by a hydrologic regime altered by the damming of the Peace River. The objective of this model is to simulate the dynamics of biomass production and litter accumulation under the forces of fire, flooding, and grazing. The model is a dynamic (state-dependent) type that emphasizes causal-functional relationships among variables. The driving variables include season (based on a weekly time step), air and soil temperatures and disturbance agent. Major state variables will include above and below ground living and dead biomass. The simulation period is ten years. The simulation exercise is to be verified through short-term experimental studies and survey sampling designed to test the key functional relationships in the model and to calibrate the model state variables. When the model appears to capture the dynamics of the system, fire regimes can be explored to evaluate biomass accumulation in terms of bison forage quality and quantity, and in terms of fuels.

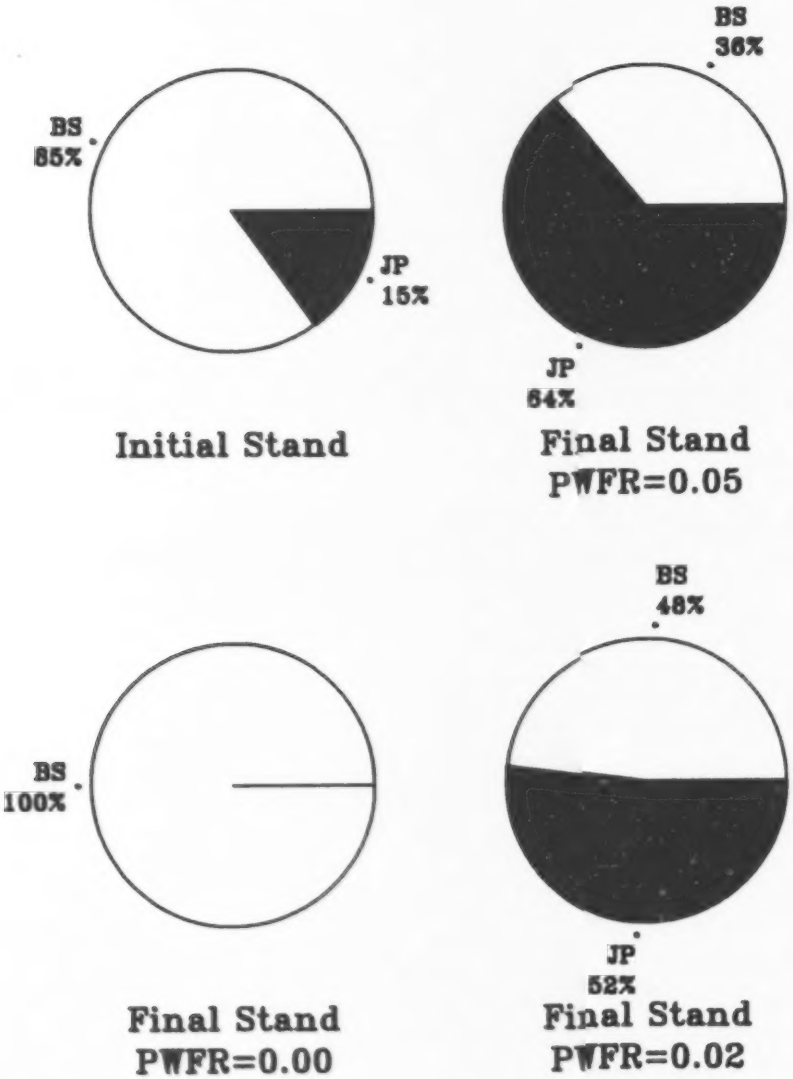
RESULTS

To test BURN, a stand representing an area in the northwestern region of the park was simulated for 500 years under three different fire regimes, using data from the WOODBUFF geographic information database. The stand composition is based on the forested portion of polygon number 876 in Universal Transverse Mercator (UTM) zone 11; with 634405, 6697142 as coordinates of its central point. Black spruce is the most dominant species (85 per cent of total biomass) while jack pine comprises the remainder of the biomass in the stand. Figure 17.1 shows the initial stand composition and the final stand compositions at the end of the three simulations. The fire regimes differed only in the fire frequency parameter which controls the period between fires (annual probability of wildfires [PWFR]). All other parameters were kept constant. As the PWFR parameter increased (simulating more frequent fires or shorter period between fires) jack pine biomass increased and became the more dominant species at the expense of black spruce. A fire regime of approximately one fire every 50 years (PWFR = 0.02) produced and maintained a mixed stand (equally dominated by both species). In the absence of fire (PWFR = 0.00) and in less than 200 years, jack pine was completely removed from the stand thus supporting the forest regeneration hypothesis of Wein (1983). Finally, the relative change in species composition supports field sites where the fire frequency has been documented.

Spatial Interpretation Of The Model's Output

The temporal output of the model presented in Figure 17.1 is based on the mean stand made by averaging the results of a number of simulation replicates in each treatment. These simulation replicates account for the different, yet possible, model outcome due to the stochastic nature of the model structure. However, these replicates can be viewed as a group of adjacent patches of stands in an area with some common characteristics such as fire frequency. For this exercise, 100 replicates were simulated in each of the three different fire behaviour treatments and the resulting stands were classified according to their most dominant forest type (Table 17.1). It is obvious that the overall dominance of jack pine biomass in the mean stand (PWFR = 0.05) presented in Figure 17.1 is due to its dominance in approximately half the number of simulated patches. On the other hand, where the two species had approximately the same biomass (PWFR = 0.02) (Figure 17.1), they were not equally distributed in terms of the number of patches

FIGURE 17.1: STAND DYNAMICS IN RESPONSE TO DIFFERENT FIRE REGIMES



Note: Initial stand composition (upper left pie diagram) is based on percentages of species biomass (BS = Black Spruce; JP = Jack Pine). The other pie diagrams are the mean final stand composition at the end of 500 years of simulations under three different annual probabilities of wildfires (PWFR) of 0.05, 0.02 and 0.00, representing a mean between fire period of 20, 50 and 0 years, respectively.

TABLE 17.1: PER CENT OF STAND REPLICATES BY DOMINANT FOREST TYPE[1]

DOMINANT FOREST TYPE	PWFR VALUES 0.05[2]	0.02[3]	0.00[4]
Black Spruce	54	74	100
Jack Pine	46	26	0

1 At the end of 500 years of simulation under different fire regimes
2 One fire every 20 years
3 One fire every 50 years
4 No fire

where each forest type was dominant. Thus, studying these patches show not only the distribution of the dominant forest types under a particular treatment, but also the less dominant, but common, types among the different treatments. These common types can be considered the ecotonal forest types among the dominant ones.

This interpretation of these stand replicates should be considered in line with the tally sheets collected after sampling a large area with some site factors. The present model appears to capture the dynamics of the system in that the output appears reasonable and it matches the forest composition data that were gathered independently.

The meadow vegetation model now being constructed will enable us to explore the forage and fuel production of the meadow vegetation types given the expected changes in flooding and fire regimes. It is hypothesized that the decrease in flood water height early in the year will lead to greater drying of the soils and thus a higher probability of severe fires. The deep-burning fires of 1981 attest to this. This example raises the hypothesis that these deep-burning fires may change the vegetation from an organic soil-dominated sedge type to a mineral soil-dominated prairie type.

DISCUSSION

Temporal Models

The forest dynamics model has been useful in exploring post-fire natural dynamics under a wide range of fire regimes and assists in understanding the stand types now found in the park. The model can now be turned to evaluating other ecological questions; for instance, it has been hypothesized that severe fires can change the forest stand type for at least one generation of trees (Wein, 1983). It has also been hypothesized that this changed stand type can be maintained or changed given specific frequencies of fire.

Another application of the model will be to examine the origin of some unusual vegetation types that are thought to have arisen by irregular or even regular use of fire by aboriginal peoples. For example, there are several areas of forest (more than 100 km^2) that are even-aged trembling aspen. Historic records suggest that native Canadians burned this area before fire control laws were enforced. These stands have arisen since controlled burning ceased.

The forest model can also be used to explore conservation problems facing park managers. For instance, if it can be shown that certain types of rare or endangered species require certain types of habitat, then fire behaviour can be applied in the model to determine what combinations of fire frequency, intensity and severity will give the proper type of habitat for these animal species. This type of exercise need not be applied only to rare or endangered species because other mammals and birds may require habitat to maintain a particular population level.

Temporal and Spatial Models

The above relates mainly to temporal models but in many biological studies there is a spatial dimension. By linking these models

to the spatial attributes in our geographic information system described by Jacobs et al. (1988), the vegetation for a number of management units could be predicted into the future. This would be useful to obtain a mental picture of what the landscape would look like in 5, 25 or 100 years into the future. This work is especially useful in predicting future animal populations given the stages of succession on the landscape at the present time. It would enable researchers to answer the question "What are the predicted population changes in this given piece of landscape if there is total fire exclusion for the next 50 years?". If model output does not meet the goals established for that area, then the fire suppression approach must be modified. A similar approach could be used to understand better the quantity of fuel and its distribution over the landscape given the same type of fire suppression scenario.

CONCLUSIONS

Modelling approaches are extremely useful to organize available information to determine what information is lacking. This assists in directing future research efforts efficiently. These exercises are useful in exploring the essential dynamics of the system without becoming submerged in confusing details that tend to arise through survey methodologies. From a practical point of view, modelling exercises are useful to evaluate management options before implementing those options. Modelling in time and space is a recent and developing field of research and management activity. The recent formation of landscape science societies and the increasing number of publications attest to the perceived usefulness of the approaches.

ACKNOWLEDGMENTS

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18

A CELLULAR FIRE GROWTH MODEL TO PREDICT ALTERED LANDSCAPE PATTERNS

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ABSTRACT

Fire is a major force in landscape dynamics that alters induced vegetation patterns. This paper describes a microcomputer-based simulation model that grows fire on heterogeneous landscapes under varying weather conditions. The model is driven by the components of the Canadian Forest Fire Danger Rating System and grows according to a grid pattern of homogeneous fuel cells. The model provides a visual and tabular output of fire area and perimeter location over time for a specific piece of landscape. It thus provides the first necessary step in forecasting the impact of potential wildfire or planned prescribed fire in landscape management.

INTRODUCTION

Landscape dynamics are driven by interacting endogenous and exogenous forces acting at the single organism level to the ecosystem level (Oliver, 1981; Shugart, 1984; White, 1979). Probably the most powerful of these forces is fire, which can encompass hundreds of thousands of hectares and attain energy output rates of up to 100,000 kW/m in a single event (Ahlgren and Ahlgren, 1960; Chandler et al., 1983; Mooney and Conrad, 1977; Gill et al., 1981; Heinselman, 1973; Komarek, 1976; Kozlowski and Ahlgren, 1974; Lotan et al., 1983; Rowe and Scotter, 1973; Slaughter et al., 1971; Van Wagner, 1978; Viereck, 1973; Wright and Bailey, 1982).

Landscapes are composed of two superimposed patterns: an inherent pattern controlled by geomorphic factors, and an induced pattern comprising developmental stages controlled by forces such as fire (Ward, et al., 1979). In the boreal woodlands, for example, the former comprises site or habitat, represents longer-term dynamics, and is associated with species composition, while the latter comprises fire frequency, represents shorter-term dynamics, and is associated with species abundance (Johnson, 1981).

Intervention in landscape dynamics, such as in resource management, requires, as a first step, the capability to forecast future patterns. Since fire is such a powerful and prevalent force, the first step in forecasting for fire-prone environments is to forecast the extent and impact of possible fires on landscape patterns. This requires reliable models of fire growth that can be applied to heterogeneous landscapes.

Existing models or systems take one of three forms:

1. equations that generate downwind rates of spread (Andrews, 1986; Burgan and Rothermel, 1984; Deeming et al., 1978;

Frandsen, 1974; Frandsen and Andrews, 1979; Muraro, 1971; Quintilio, 1972; Rothermel, 1972 and 1983; Stocks, 1972; Van Wagner, 1973),

2. superimposition of geometric shapes such as the ellipse on forward rates of spread to predict rear and lateral rates of spread as well as fire area and perimeter (Alexander, 1985; Alexander et al., 1984; Anderson, 1983 and 1984; Bunton, 1980; Lawson et al., 1985; Martell et al., 1984; Quintilio and Anderson, 1976; Simard and Young, 1978; Van Wagner, 1969), and
3. growth of the fire across a matrix of fuel cells using fire spread equations and simple geometric shapes (Kourtz 1984; Kourtz and O'Regan, 1977; Kourtz et al., 1977; O'Regan et al., 1976).

While fire spread equations are necessary for all approaches, they do not in themselves provide the fire area or the location of the total perimeter.

The geometric shape of free-spreading fires has undergone considerable investigation, and a number of shapes have been proposed including the simple ellipse (Anderson, 1983 and 1984; McArthur, 1966; Van Wagner, 1969), the double ellipse (Albini, 1976), and the ovoid (Peet, 1967). The general consensus is that the ellipse is probably the most simple and efficient shape for fires burning in continuous and homogeneous fuels on level topography, particularly as they increase in size and intensity (Alexander, 1985; Anderson, 1984; Green, 1983; Green et al., 1983). However, the use of a single ellipse to define total fire perimeter and area in fires burning through heterogeneous fuels under varying conditions of weather, fuel moisture and topography becomes unmanageable and can lead to major errors.

The only approach with the potential to handle heterogeneous fuels and varying conditions in a realistic manner is the cellular one developed by Kourtz et al. (1977). Published reports on the Kourtz model, however, indicate that considerable improvements can be made with respect to the error associated with number of adjacent cells, fire spread in relation to major axes of adjacency, criteria for connecting axes limits, lateral and rear rates of spread, terrain effects, stochastic as opposed to deterministic outputs, and linkage to immediate fire effects.

The objective of the model presented here is to provide the manager with a realistic visual and tabular prediction of fire area and perimeter location, based on the fuel types and spread rates of the Canadian Forest Fire Danger Rating System. The model has potential as a decision-aid for pre-suppression planning, longer-term suppression strategy, real-time suppression tactics, resource allocation and distribution, design and use of prescribed fire, and as a predictor of fire effects and changed landscape patterns.

MODEL DESCRIPTION

The model simulates fire growth in heterogeneous fuels under varying weather conditions for periods of up to five days. The Canadian Forest Fire Behaviour Prediction System (FBP) (Lawson et al., 1985) and the Canadian Forest Fire Weather Index System (FWI) (Van Wagner and Pickett, 1985) are used to link weather to fuel type to yield spread rates.

The model runs on any IBM PC equipped with a colour graphics card, although an IBM AT or compatible is recommended for superior performance. Output of fire growth is in the form of graphic displays of fire perimeter superimposed on forest maps. Graphical output of spread rates in each fuel type is also displayed. The computer programs used to implement this model can be divided into three distinct phases.

Mapping Phase

The first phase deals with the creation and storage of forest maps on the computer.

The creation of forest maps is carried out by a program which allows the user, by use of "arrow keys" and "cursor movement" to outline stand boundaries and to fill these boundaries with one of a selection of cover types. No restrictions exist on the number, complexity or location of the stands and barriers input by the user. The selection of cover type however, is restricted to one of the 14 fuel types described in the FBP, with the addition of the "lake" and "rock" cover types (i.e., barriers to fire spread). The process of creating maps in this manner is relatively slow if a complex forest configuration is to be entered, but it involves no special equipment such as digitizers or digitizing tablets, etc. However, the option exists to use a digitizing tablet. One of the areas for future improvement to the model involves linking the model directly to a geographic information system which would contain the required forest maps.

Pre-Ignition Phase

The second phase (pre-ignition) involves entering the weather conditions under which the model is to run. The weather conditions required by the model include noon values of the following: temperature, relative humidity, wind speed, wind direction, the total rain accumulated in the previous 24 hour period and the times at which rain began and ended. Once the weather data has been entered, diurnal patterns are calculated which estimate the weather conditions throughout the 24 hour diurnal cycle at hourly intervals. Since these patterns are based on standard weather trends they will not reflect the passing of frontal systems nor will they reflect unusual weather conditions. In the event unusual weather conditions do occur, the diurnal patterns may be replaced with any values the user desires. The resulting weather patterns are used to calculate the initial spread index (ISI) values from the FWI which are then used in conjunction with the FBP to calculate the spread rates for each of the 14 fuel types. These spread rates are stored in disk files from which they are automatically retrieved when necessary.

Post-Ignition Phase

The third phase (post-ignition) deals with the actual spread of the fire or fires and any suppression activities a user may wish to attempt. The routines in this phase allow fire locations to be chosen and fire lines to be constructed by use of the arrow keys and cursor movement. No restrictions exist with respect to the number or location of fires which may be started nor do any restrictions exist on the location and length of fire lines.

At present it is assumed that a fire line will stop fire advance completely regardless of any burning conditions. Future improvements to the model include eliminating this assumption to make the success rate of fire lines a probabilistic function based on rates of spread, fuel type and wind speed. In addition, fire line productivity rates will be incorporated as they become available.

MODEL STRUCTURE AND FUNCTION

The model base is a cellular grid structure, in which each 100 m x 100 m cell is occupied by one of the 14 fuel types currently defined by the FBP. The model employs the concept of elliptical fire growth where the lateral rate of spread is a function of the forward and back rates of spread.

The grid structure of the forest fuel data requires that a precise definition as to which cells are adjacent to a burning cell must be established. Simply stating that cells which share an edge are adjacent is not a suitable definition since it is too restrictive.

Two factors are important in defining an adjacent cell:

1. the location of an adjacent cell relative to a burning cell (Figure 18.1), and
2. the direction of the adjacent cell relative to a burning cell (Figure 18.2).

FIGURE 18.1: LOCATION OF ADJACENT CELLS RELATIVE TO A BURNING CELL

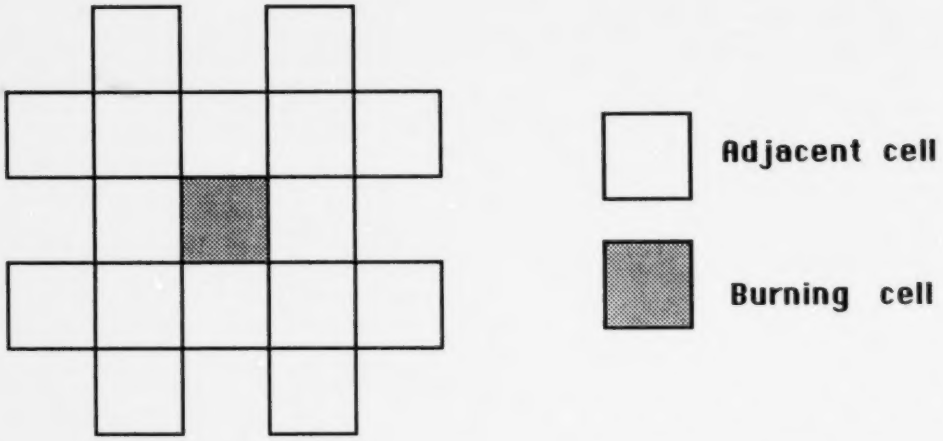
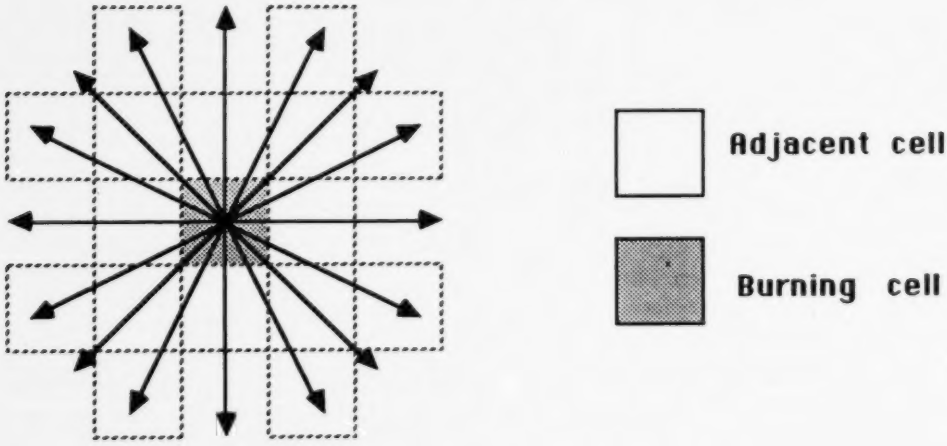


FIGURE 18.2: DIRECTION OF ADJACENT CELLS RELATIVE TO A BURNING CELL ALONG 16 DIRECTIONAL AXES



Note: Only 8 of the 16 adjacent cells are physically touching the burning cell.

Note that 16 cells are defined as adjacent and that only 8 of these are physically touching the burning cell.

The definition of adjacency is important because this definition plays a major role in the error associated with the model's predicted fire size and shape. As the number of adjacent cells increases from 4 to 64 the error contained in the predicted fire shape decreases, but the computational load increases exponentially. In this model, 16 cells are defined as adjacent, since this is considered the optimum compromise between error and computational speed.

Pre-Ignition Calculations

Diurnal Weather Patterns

Some means of accounting for the daily variation in fire danger is essential, since the model is designed to predict fire growth for up to five days after ignition. The weather parameters throughout that period; temperature, wind speed, humidity, etc., all vary, but are rarely available.

For these reasons the model has routines which, when given actual or predicted noon weather values will calculate the hourly diurnal weather patterns which are likely to be present over the length of the fire simulation. These patterns will not reflect sudden weather changes (i.e., frontal systems) and so, once the patterns have been calculated, they may be modified or replaced if so desired.

Current and predicted noon weather values must be entered before any patterns can be calculated. The values required are: temperature, relative humidity, wind speed and the amount of rain accumulated since noon the previous day. If the amount of rain accumulated is greater than 0.5 mm then the time at which the rain began and the time at which the rain stopped must also be entered. The weather values as well as an initial Fine Fuel Moisture Code (FFMC), Drought Code (DC), and Duff Moisture Code (DMC) are used to calculate the Fire Weather Indices using the equations found in Van Wagner and Pickett (1985). The calculated indices are deemed valid for the period 12:00 to 16:00 only (Van Wagner, 1977) and therefore further calculations are required.

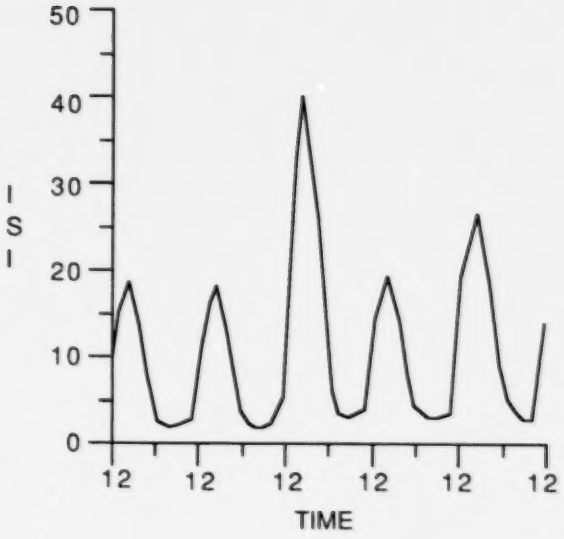
The model uses two routines to estimate the variation in the FFMC; a dry weather routine and a wet weather routine. Van Wagner (1972) presented a table of diurnal variation in the FFMC which relies on the condition that there is no appreciable rainfall throughout the day. This table is used by the model as the dry weather routine. The wet weather routine is based on the procedures outlined in Van Wagner (1977).

The table presented by Van Wagner (1972) gives the FFMC for 8 time periods throughout a 24 hour period instead of the hourly intervals required by the model. For time values between those listed in the table, a straight line interpolation is carried out. To calculate the FFMC values in the period 06:00 to 11:00 one of three possible values must be selected from the table, the possibilities depending on the humidity at that time. The dry weather routine selects the FFMC among the three choices which will cause the 11:00 FFMC to match as closely as possible to the FFMC value for noon the next day. The result is a curve representing the FFMC at all times from 12:00 through to 11:00 the next morning.

Whenever the total rainfall for a 24 hour period exceeds 0.5 mm the wet weather routine presented by Van Wagner (1977) is followed. The wet weather routine requires additional weather data which may not be available and these values are therefore estimated using the standard daily trends for humidity, temperature and wind speed presented in Turner and Lawson (1978). These estimated values are used to calculate the FFMC for the period when rain was falling. For times before the rain began the FFMC values are calculated using the dry

weather routine outlined above. After the rain has stopped, the FFMC values are linearly interpolated using FFMC at the time the rain stopped and the FFMC for noon the next day as end points. Using the diurnal FFMC values and the estimated diurnal wind speeds, hourly ISI values are computed (Figure 18.3). In addition the diurnal FFMC values are used to compute hourly no wind ISI values.

FIGURE 18.3: DIURNAL VARIATION IN THE INITIAL SPREAD INDEX OVER A 5 DAY PERIOD



Note: ISI = Initial Spread Index
12 = Noon

Wind Corrections

This model treats the fire shape as an ellipse whose major axis is the sum of the forward rate of spread (FROS) and the back rate of spread (BROS), and whose minor axis is the sum of the two lateral rates of spread (LROS). The FROS is calculated using the ISI and the equations in the FBP while the BROS is calculated using the no wind ISI and the equations in the FBP. The LROS is calculated using the following simple equation derived from unpublished experimental data of Fons as presented by Anderson (1983).

$$LROS = [(4.579X+19.413)/(22.992+X)] \times BROS$$

where: $X = FROS/BROS$

The standard ellipse is shifted and rotated to obtain the equation which is used to calculate the distances the fire must spread from the point of ignition to the fire perimeter. The ellipse is rotated so that its major axis is parallel to the wind direction.

After calculating the distances from the point of ignition to the fire perimeter for each of the 16 directions, the largest value is taken as 100 per cent and all the others are converted to a percentage of the largest one. The resulting values are used as multiplication factors which represent the wind's effect on the rates of spread in given directions.

The wind correction factors are calculated once for every hour the simulation is to run. The result is a table indexed by time (in hours) and direction (one direction for each adjacent cell).

Spread Times

Terms used in the calculations are defined as follows.

1. Spread Times: The length of time required for a fire to spread from a burning cell to an adjacent one. These times are calculated using the rate of spread equations found in the **User guide to the Canadian forest fire behaviour prediction system: Rate of spread relationships** (Alexander et al., 1984).
2. Wind Correction Factor: A multiplication

factor reflecting the wind's effect on the ROS in a given direction.

3. Corrected Distance: The distance from the centre of a burning cell to the centre of an adjacent cell. This distance reflects the extra distance a fire must spread when moving diagonally rather than horizontally or vertically.

To calculate spread times the following algorithm is performed for each combination of fuel type and spread direction.

1. The wind correction factor for hour X is multiplied by the ROS for hour X to yield "temporary distance".
2. If the temporary distance is greater than the "corrected distance" the calculations proceed to Step 6.
3. The hour index is increased by one (i.e., X = X + 1).
4. The wind correction factor for hour X is multiplied by the ROS for hour X and this value is added to temporary distance.
5. Return to Step 2.
6. By comparing the original value of X to the final value of X and by comparing temporary distance to corrected distance the number of hours and minutes needed for the fire to spread across the cell is calculated.

Spread times are calculated for each interval of the fire simulation (12 minutes). This interval, although chosen arbitrarily, is small enough to ensure that round-off errors are kept to a minimum. The resulting values are stored in a table which is indexed by time, direction and fuel type.

Post-Ignition Calculations

The Fire Spread Algorithm

At present the model makes two key assumptions regarding fire spread:

1. if a cell is burning, the adjacent cells will burn at a rate independent of the fuel in the burning cell, and
2. as the fire spreads the perimeter is treated as a collection of point sources, each burning independent of any neighbouring burning cells. These assumptions are necessary to simplify the simulation process but are the source of some model error.

The algorithm below uses four terms which are defined as follows.

1. Time Value: A number value associated with each cell of the map. This number represents the time at which the fire reached the centre of that cell.
2. Current Time: The time at which the model is calculating fire spread. Current time begins at 0 and increases to a maximum of 120 hours.
3. Interval: The elapsed time between visual updates of the fire perimeter.
4. Burning cell: Any cell which has a time value greater than the current time but less than the current time + interval. These are the cells where flaming point is simulated on the graphical update.

All burning cells are located and placed into a list before the spread algorithm begins. For every cell in the list of burning cells the following algorithm is performed:

1. the time required for the fire to spread to all adjacent cells (spread time) is determined,
2. the spread time is added to the time value of the burning cell,
3. if this sum is less than the time value of the adjacent cell, the time value of the adjacent cell is made equal to this summed value, and
4. if the new time value in the adjacent cell is less than current time + interval, this cell is inserted into the list of burning cells.

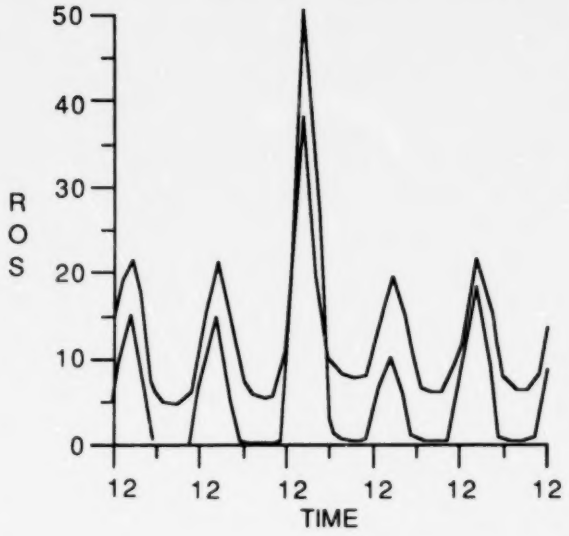
Steps 1 through 4 are repeated until no cells remain in the list of burning cells.

MODEL OUTPUT

The model outputs data in one of two forms. The first is in the form of graphs showing the spread rates for each of the fuel types versus time (Figure 18.4).

The second is in the form of forest maps showing the exact location of the fire over time (Figure 18.5, Figure 18.6, Figure 18.7). The position of the fire is indicated by two colours, red and yellow, or two shades of grey, depending on the equipment available. The outer band of the fire location represents the hourly increment of the fire's growth, and therefore provides a qualitative estimate of the fire's rate of speed.

FIGURE 18.4: DIURNAL VARIATION IN RATE OF SPREAD OVER 5 DAYS FOR 2 DIFFERENT FUEL TYPES



Note: ROS = Rate of Spread
12 = Noon

SUMMARY

The fire spread model provides the resource manager with a means for predicting the future landscape patterns which result from fires burning over heterogeneous landscapes. The predictions are in the form of visual and tabular output in fire area and perimeter location over time and are based on the Canadian Forest Fire Danger Rating System (CFFDRS), fuel configuration, suppression attempts and varying weather conditions.

It should be noted that the model presented is still in the early stages of development and that several additions are planned to improve its accuracy and its ability to predict actual fire spread. These additions include: terrain affect on fire spread, probabilistic functions to evaluate fire line effectiveness, functions to evaluate fire line construction rates, improvements to the estimation of rear and lateral rates of spread, improvements to the definition of adjacency, and stochastic as opposed to the current deterministic output. Future work will also include attempts to validate the model's predictions against actual fires. The first level of validation will involve comparing the model's predicted fire patterns to the patterns created by a series of small laboratory test fires burned in heterogeneous fuels. The second level of validation will involve comparing the model's output to well-documented historical fires.

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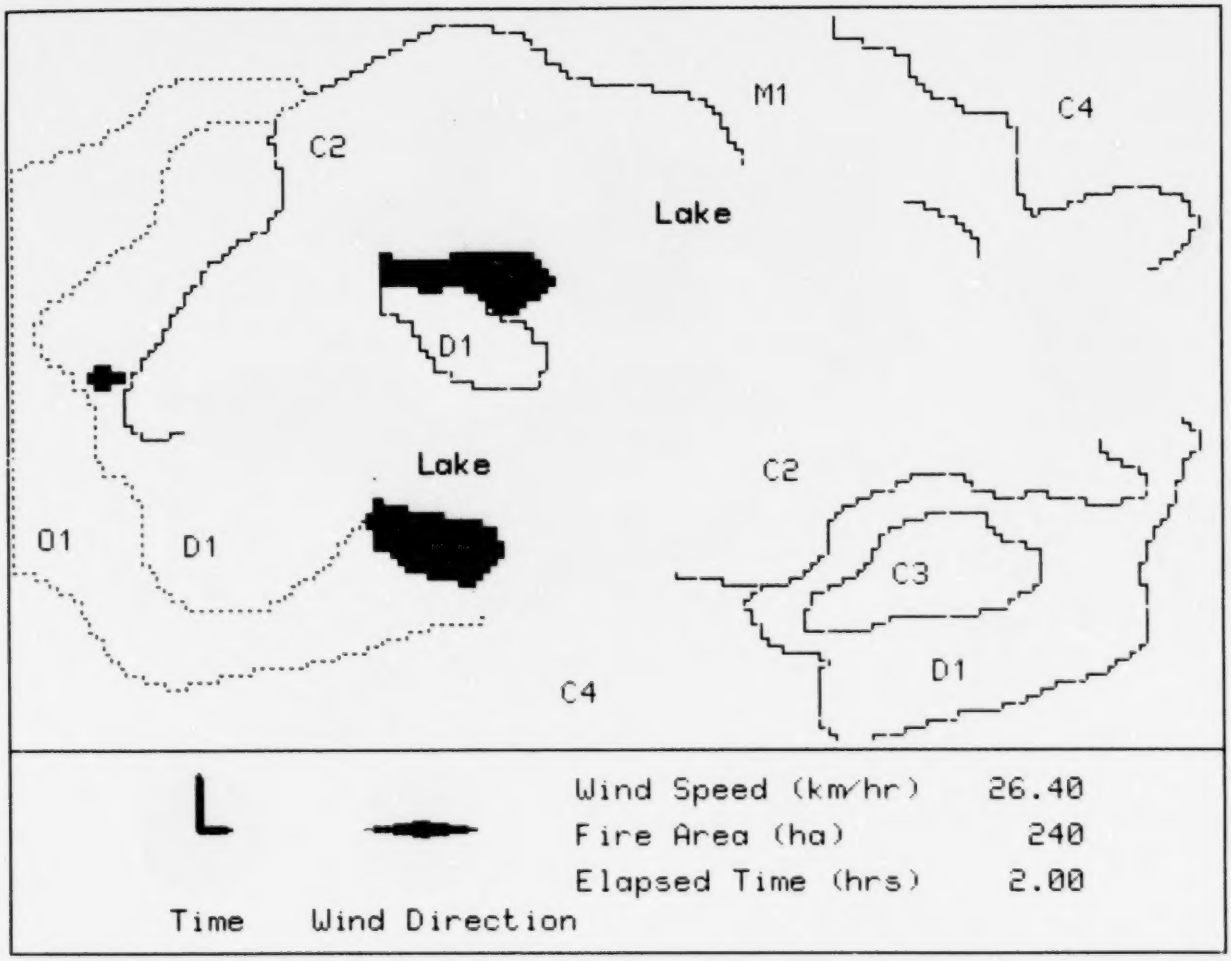
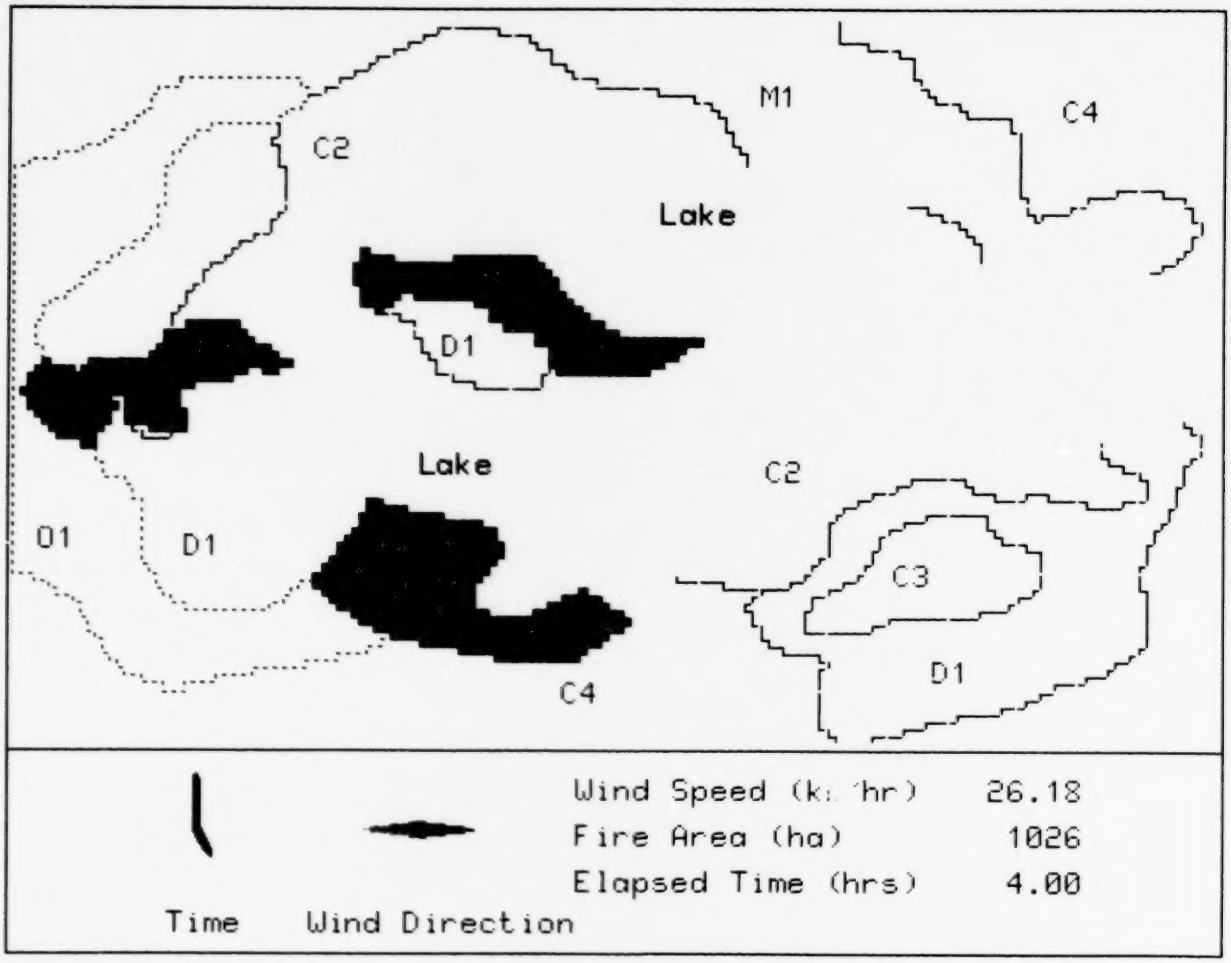
FIGURE 18.5: FIRE LOCATIONS AND PERIMETERS 2 HOURS AFTER IGNITION IN A HETEROGENEOUS FUEL (VEGETATION) COMPLEX



Note: Black area indicates spread in the previous hour

C2 = Boreal Spruce	D1 = Leafless Aspen
C3 = Mature Jack Pine	M1 = Boreal Mixedwood
C4 = Immature Jack Pine	O1 = Grass

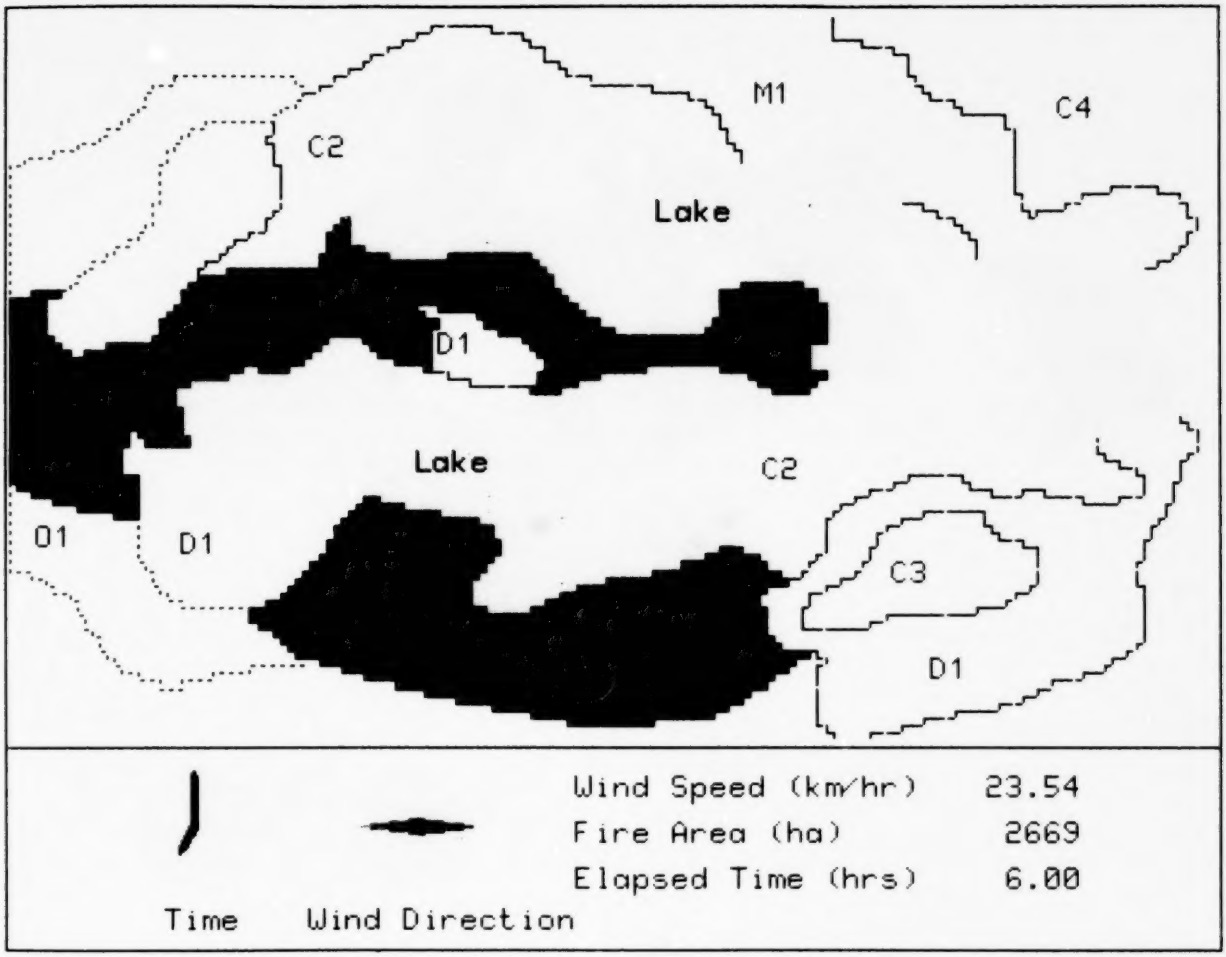
FIGURE 18.6: FIRE LOCATIONS AND PERIMETERS 4 HOURS AFTER IGNITION IN A HETEROGENEOUS FUEL COMPLEX



Note: Black area indicates spread in the previous hour

C2 = Boreal Spruce	D1 = Leafless Aspen
C3 = Mature Jack Pine	M1 = Boreal Mixedwood
C4 = Immature Jack Pine	O1 = Grass

FIGURE 18.7: FIRE LOCATIONS AND PERIMETERS 6 HOURS AFTER IGNITION IN A HETEROGENEOUS FUEL COMPLEX



Note: Black area indicates spread in the previous hour

C2 = Boreal Spruce	D1 = Leafless Aspen
C3 = Mature Jack Pine	M1 = Boreal Mixedwood
C4 = Immature Jack Pine	O1 = Grass

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19

THE APPLICATION OF A SPREADSHEET FORMATTING PROCEDURE IN THE DEVELOPMENT AND IMPLEMENTATION OF A HABITAT EVALUATION MODEL FOR THE NORTHWEST TERRITORIES

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ABSTRACT

The results from a project designed to test the applicability of using a commercially available spreadsheet program, Appleworks™, to develop and implement a habitat evaluation model in the Northwest Territories is presented. A habitat-species evaluation model was adapted from an existing model presently being employed in Alberta. The study area is located within Nahanni National Park Reserve in the southwestern portion of the Northwest Territories. The Nahanni National Park Integrated Survey of Biophysical Resources was used as a source of habitat data (e.g., vegetation, geomorphology, and topography). We selected moose (*Alces alces*) as the species of investigation, and obtained multiyear distribution data from the Parks Canada computerized database. The model is preliminary, and should be interpreted with this fact in mind; refinement will be completed during future iterations of this procedure. Advantages of this approach to modelling include: the "user-friendly" nature of the software, the copy function which facilitates rapid deployment of similar or exact copies of desired formulas, the edit function which enhances the iterative interaction between the modeller and the computer, and the flexibility in data manipulation and viewing functions. Limitations of this approach can include the insufficient memory and storage capacity of the computer, and the limited number of mathematical functions available to the modeller. The memory limitation can be overcome by providing additional memory to the computer or by splitting the files. The applicability of the habitat evaluation model is discussed.

INTRODUCTION

The use of computer models in resource management has developed rapidly in the last two decades. Recently, considerable emphasis has been placed on the introduction of "user-friendly" microcomputers into the workplace. In addition, user-friendly software, designed for professionals with little computer training, has enhanced the manager's ability to implement highly technical projects at the work station (Gray, 1986a).

The spreadsheet program is one example of a commercially available software package which can be used to address a variety of resource management issues. Eedy et al. (1986) used a spreadsheet program to model radiological impacts from isotope disposal in municipal waste systems in Southern Ontario. Silvert (1983a) used a similar program to generate an ecological model, and recommended it as a teaching tool (Silvert, 1983b). Olsthoorn (1985, p. 381) suggested that spreadsheet programs are "... forerunners of new general software ... suitable to do almost any job, where only the fantasy of the user limits the possibilities". He used a

spreadsheet program to construct groundwater models.

The purpose of this project was to test the suitability of a commercially available spreadsheet program, Appleworks™, for the development and application of a wildlife habitat evaluation model in the Northwest Territories. Wildlife habitat evaluation models assist resource managers to determine wildlife population-habitat relationships and to make decisions within the context of environmental management and land-use planning. This project is one component of a program designed to examine the feasibility of using existing ecological (biophysical) data collected according to the principles of the Ecological Land Classification (ELC) system (Wiken et al., 1980) and wildlife data, to estimate wildlife habitat suitability (Gray, 1986b). In addition to testing the applicability of the spreadsheet program, our goal was to modify and adopt a modelling procedure in order to calculate habitat suitability, make a prediction about the distribution of moose (*Alces alces*) on the basis of habitat suitability indices, and evaluate the validity of the model by subjectively comparing moose distribution and habitat suitability values by employing a simple overlay technique. We make preliminary observations on the suitability of this type of habitat evaluation model to the Northwest Territories.

STUDY AREA

The study area is located within Nahanni National Park Reserve in the southwestern Northwest Territories (Figure 19.1). Bostock (1948) included this area within the northeastern section of the Cordilleran Region. The area comprises mountain ranges, elevated plateaus, rolling hills, broad depressions, and incised river valleys (Gimbarzevsky et al., 1979). Sedimentary rock formations dominate, and occur as limestone, dolomite, shale, and sandstone.

The study area is influenced by a continental climate of short, warm summers and long, cold winters (Miller et al., 1982; Parks Canada, 1984). Within Nahanni, the annual precipitation ranges from 34.5 cm in the east to 56.2 cm in the west (Gimbarzevsky et al., 1979). The air masses lose water over the higher mountain ranges in the west as they move in an easterly direction. The frostfree period is extremely short and at lower elevations (e.g., valleys), July is the only month during which frost does not normally occur (Gimbarzevsky et al., 1979).

The area is characteristic of the alpine-tundra section of the Boreal Forest Region (Rowe, 1972). The vegetation consists of plant associations commonly found in arctic tundra, alpine tundra, and boreal forest communities (Wiken, 1986).

METHODS

Species-Habitat Evaluation Model

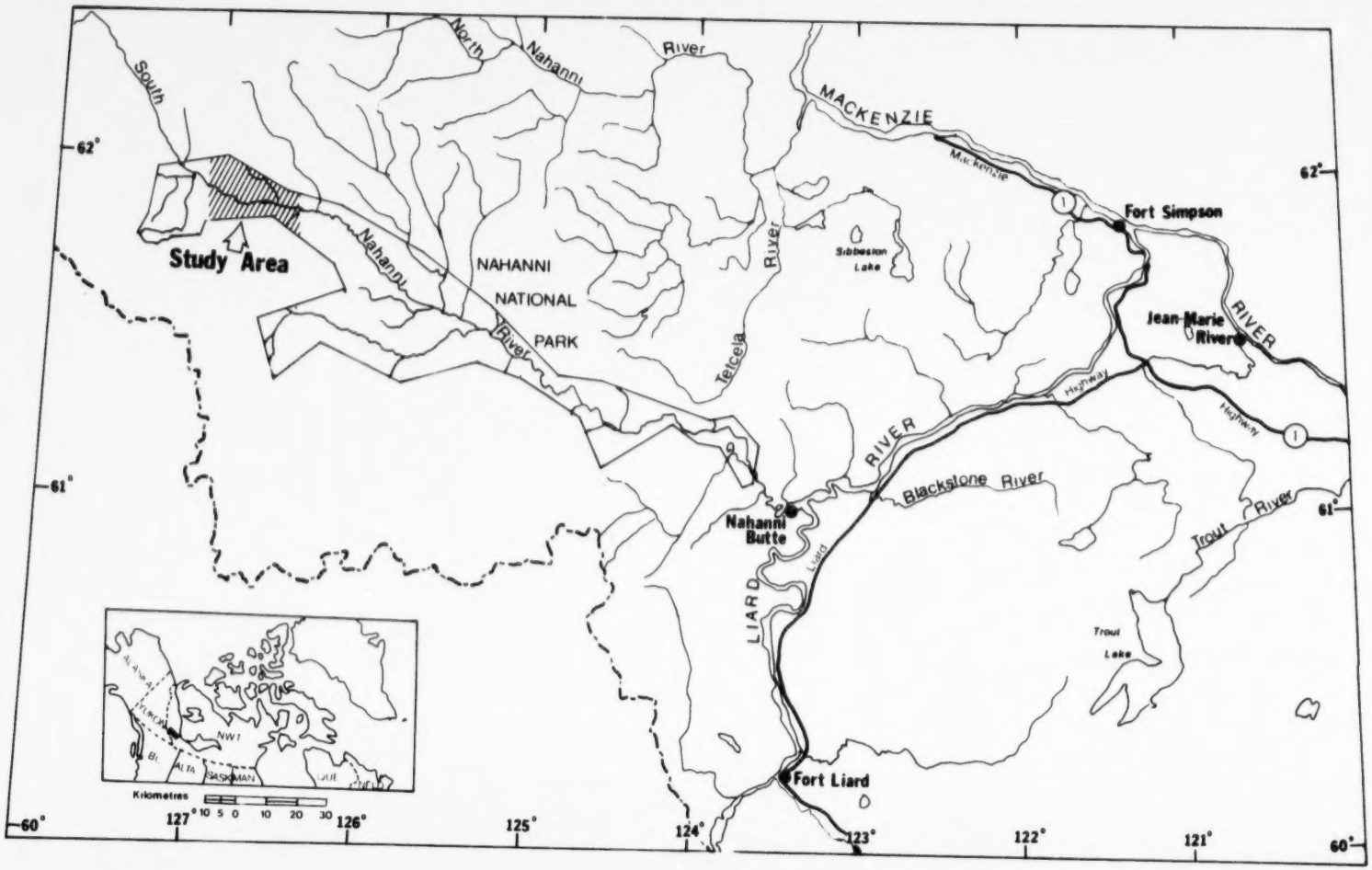
The model was adapted from an existing model presently being tested in Alberta (Eng and Stelfox, 1985; Stelfox, 1984) and from the Habitat Evaluation Procedures (HEP) developed in the United States (Schamberger and Krohn, 1982; United States Fish and Wildlife Service, 1980). It was modified to facilitate an estimate of current habitat suitability.

Our modelling procedure is based on the concept of "decision analysis", which is a combination of objective and subjective components (Howard, 1979). It is important to keep in mind that workers in this field often make numerous subjective decisions during the collection, analyses, and interpretation of data.

The model incorporates four considerations.

1. The needs of a species are divided between seasons (spring/summer and fall/winter), and each season can be weighted according to its importance to the wildlife species. In this case, fall/winter was assigned a weight of 0.6 and spring/summer a weight of 0.4 because fall/winter is more critical to

FIGURE 19.1: LOCATION OF STUDY AREA WITHIN NAHANNI NATIONAL PARK RESERVE



the survival of moose in the study area (Table 19.1).

2. Within each season there are specific life requisites that a species must gain access to in order to survive (e.g., food, thermal cover, and escape cover). Each life requisite is weighted according to its importance (Table 19.1).
3. Life requisites are comprised of ecological variables (e.g., vegetation, topography, and geomorphology), which are weighted according to their value (Table 19.1).
4. Each ecological variable (e.g., vegetation) is divided into predetermined categories which represent the range of vegetation types found in the study area (Table 19.2). Each vegetation type, for example, is ranked (0 = Inadequate to 3 = Best) according to its suitability as a life requisite (Table 19.3).

The life requisites for the spring/summer season were: food, escape cover, and interspersion/juxtaposition. The life requisites for the fall/winter period were: food, escape cover, thermal cover, and interspersion/juxtaposition. The ecological variables included: terrestrial vegetation, aquatic vegetation, mineral licks, topography, elevation, and land structure (geomorphology). Interspersion and juxtaposition values were determined according to procedures developed by Heinen and Cross (1983). Interspersion is defined as the intermixing of land units (e.g., a high interspersion value would be applied to well-distributed land units and a low value to clumped land units), and juxtaposition is a measure of the proximity of the land units being studied (e.g., a high juxtaposition value would be applied to land units which provide a variety of habitat requirements) (Giles, 1978).

We selected the Nahanni National Park Integrated Survey of Biophysical Resources prepared by Gimbarzevsky et al. (1979) as the source of habitat data. The data was mapped and described at a scale of 1:100,000. A total of 2,038 distinct land units were identified within the boundaries of the park by Gimbarzevsky et al. (1979). We arbitrarily selected a sample area of the park (Figure 19.2), which contained 188 land units. We selected moose as the species for testing the model, and completed a literature review of habitat requirements. This species was selected because its life history lends itself to evaluation using this type of modelling procedure, and because of the senior author's experience with moose. Once the literature review was completed, the ecological variables were selected and ranked according to their value as moose habitat for different life requisites at different times of the year.

We obtained multiyear distribution data from the Parks Canada computerized database. Once the model was run, and a current habitat suitability value calculated for each land unit, the moose distribution pattern was plotted to facilitate subjective determination of the success of the model.

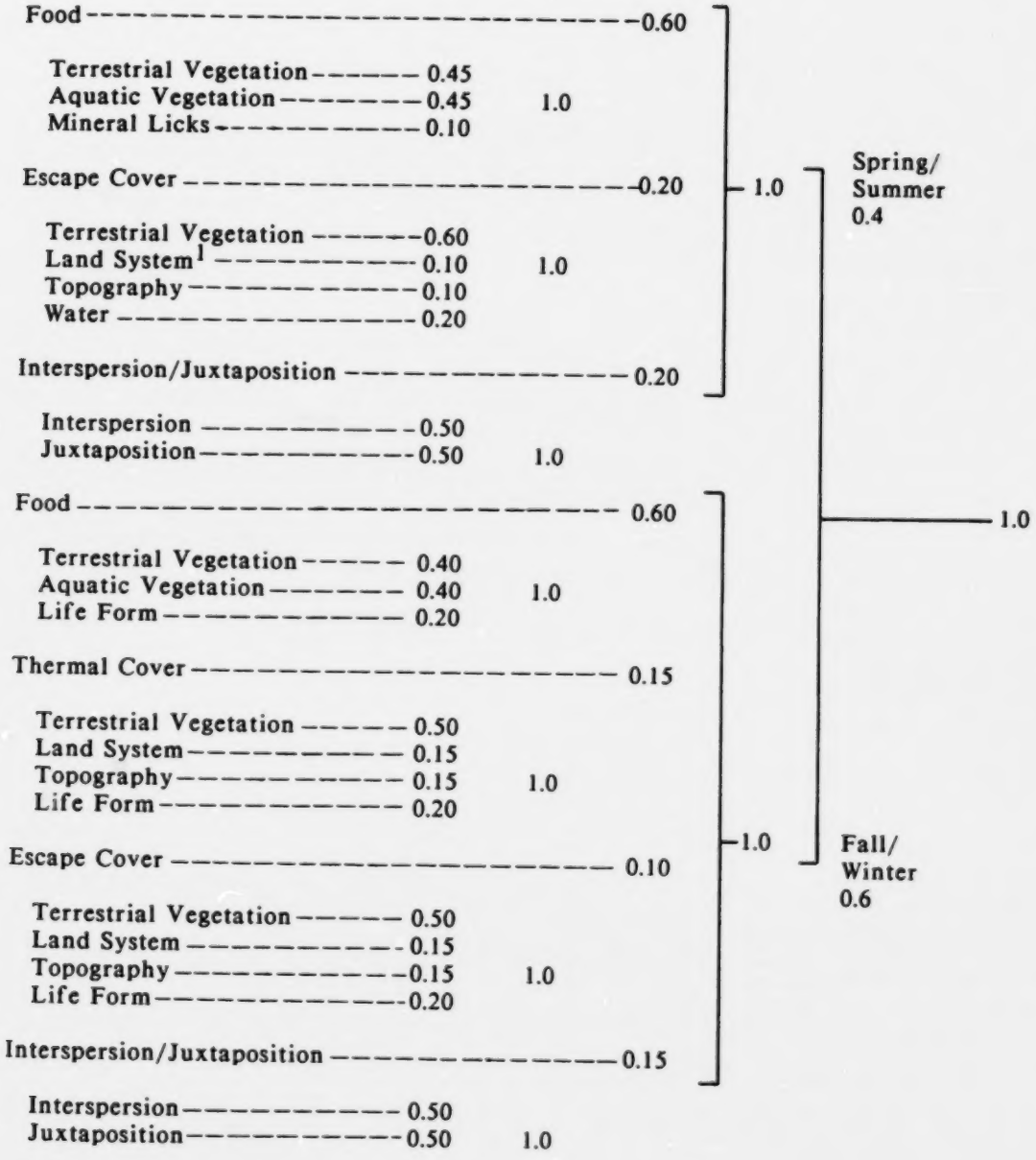
Building the Model with the Appleworks Spreadsheet

We employed an Apple IIe microcomputer with 128 K RAM, 2 disk drives, and a printer. The spreadsheet is one of three integrated programs included in the Appleworks program. The other two programs are a word processing language and a database manager.

The spreadsheet corresponds to a matrix where the columns are represented by letters and the rows by numbers. The matrix is comprised of cells; each cell can be identified according to column and row designations. Appleworks spreadsheet files can contain 127 columns and 999 rows, for a maximum of 126,873 empty cells; however, when the modeller uses an Apple computer with 64 K RAM, the maximum capacity is approximately 1,000 filled cells. When 128 K RAM is available, the maximum capacity is approximately 6,000 filled cells.

The Appleworks spreadsheet program can perform a number of simple matrix manipulations, including: + (addition), - (subtraction), / (division), * (multiplication), ^ (exponent), @ SQRT (square root), @ SUM (sum of all the values listed), @ AVG (arithmetic mean of the

TABLE 19.1: AGGREGATION WEIGHTS ASSIGNED FOR MOOSE HABITAT EVALUATION



[1] Land system describes the geomorphology of the land unit.

TABLE 19.2: AN EXAMPLE OF THE HABITAT PARAMETERS USED TO EVALUATE MOOSE HABITAT

VARIABLE CATEGORY CODES

Vegetation Cover Classes

S	- undifferentiated spruce
bS	- black spruce
P	- pine
SP	- spruce-pine
SF	- spruce-fir
PoP	- poplar/aspen-pine
PPo	- pine-poplar/aspen
SL	- spruce-larch
B	- birch
ZR	- exposed rock
ZX	- exposed soil
V	- non-treed

Life Form Classes

L	- lowlands
M	- montane
S	- subalpine
A	- alpine
N	- nival

Water

WA1	- major river with tributaries, lakes and ponds
WA2	- major river with tributaries, lakes
WA3	- major river with tributaries, ponds
WA4	- major river
WA5	- river
WA6	- stream
WA7	- intermittent stream
WA8	- ponds
WA10	- lakes
WA11	- lakes and intermittent streams
WA12	- rivers and intermittent streams
WA13	- no water

Topography

X1	- ridge, peak
X2	- high hill
X3	- high rolling hills
X4	- multiple peaks, highly dissected terrain
X5	- trough, steep valley
X6	- depressional valley with steep sides
X7	- knoll, hill
X8	- elevated rolling plateau, dissected hill

values listed), @ MAX (largest value listed), and @ MIN (smallest value listed).

Each cell can contain text, a number, or a formula. Each formula includes a reference to the location of the data to be used in the application of the formula. For example, in order to calculate the value of terrestrial vegetation as food for moose during the fall/winter period in land unit 1759, the ranked variable (3) in cell B16 is multiplied by the weighting of the ranked value (0.4) in cell C16 (Table 19.4). The product (B16*C16 = 1.2) is listed in cell D16 (Table 19.5). This value can then be used in calculations later in the program; the modeller only has to refer to the location using the column/row designation. The value of a land unit was then determined according to the value ranges developed for each habitat suitability class (e.g., Best - Inadequate). For example, using the maximum values possible for each variable, it was determined that any land unit with a value of 2.3 or higher could be classed as "Best" habitat.

ASSUMPTIONS

Assumptions resulting from this work are listed below.

1. It is assumed that the life requisites and their importance to moose were correctly identified and allocated, and that realistic importance values were assigned. These decisions were based on a literature review and personal experience. It is

TABLE 19.3: AN EXAMPLE OF VARIABLE RANKINGS FOR EACH HABITAT EVALUATION PARAMETER

MOOSE/SPRING-SUMMER/FOOD-TERRESTRIAL VEGETATION

Variable Ranking	Variable Category	Rationale
Best (3)	(PoP) (B) (Po)	Moose are browsers and feed on the stems of deciduous trees and shrubs
Moderate (2)	(PPo) (SPo)	This category is characterized by reduced presence of deciduous shrub and tree stems
Poor (1)	(P) (bSL) (S)	Significant amounts of browse are absent
Inadequate (0)	(ZR) (ZX) (V)	Non-vegetated areas retain no food

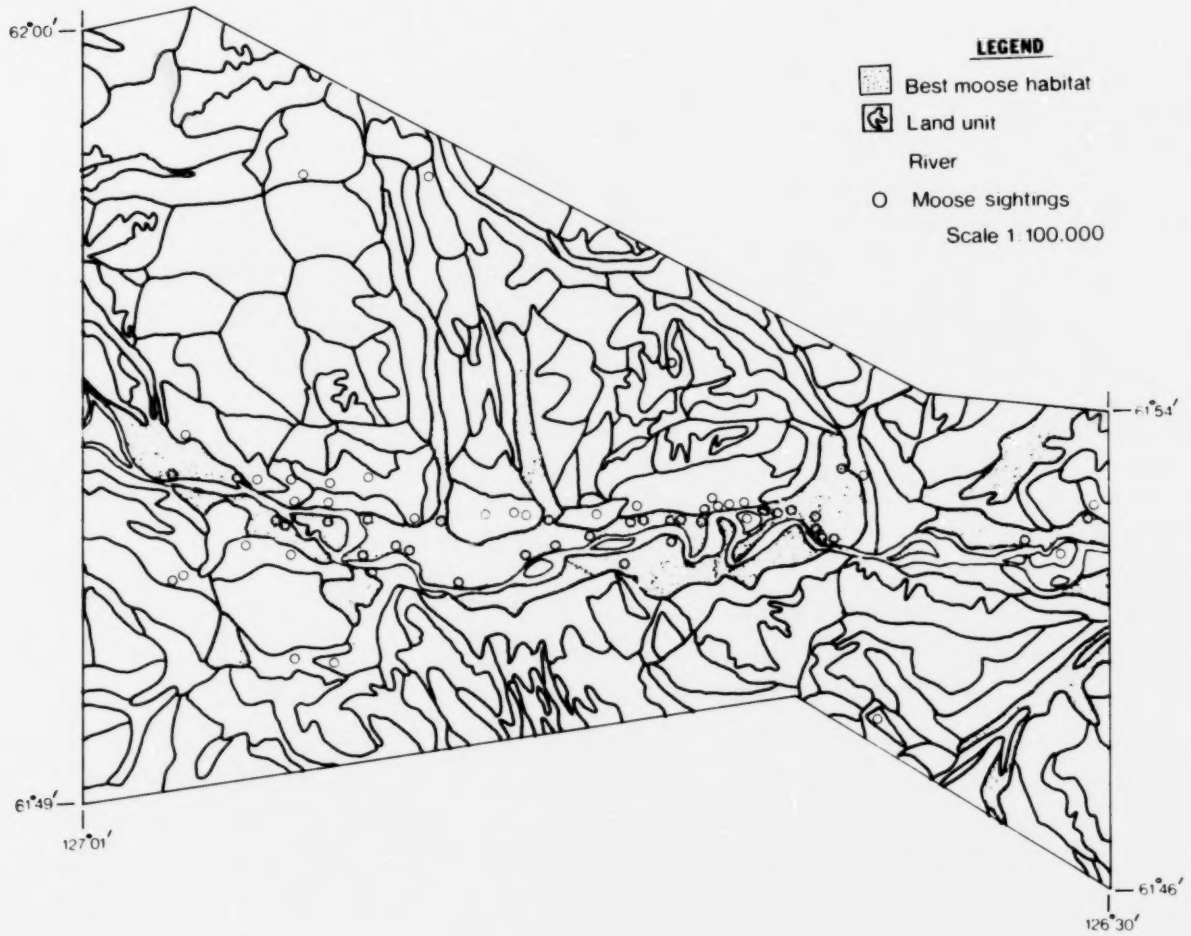
MOOSE-SPRING-SUMMER/FOOD-AQUATIC VEGETATION

Variable Ranking	Variable Category	Rationale
Best (3)	(WA1) (WA2) (WA3)	These water types provide riparian and aquatic vegetation
Moderate (2)	(WA10) (WA11)	These water types provide some riparian vegetation
Poor (1)	(WA8) (WA9)	These water types provide minimal riparian vegetation
Inadequate (0)	(WA13)	These water types retain no vegetation

not the result of statistical analyses. A statistical procedure will be implemented during future iterations of this approach (Gray, 1986b).

2. It is assumed that the relationships between variables within the system are accounted for in the model (e.g., limiting factors, cumulative relationships, compensatory relationships, and spatial relationships).
3. It is assumed that the biophysical data are valid and are accurate indicators of the degree to which a particular life requisite is provided to the species.
4. It is assumed that the land units are characterized by internal homogeneity.
5. It is assumed that the interspersion and juxtaposition values reflect the internal homogeneity of the land units.
6. It is assumed that the subjective ranking of each ecological variable is realistic and can therefore be used to complete statistical analyses.
7. It is assumed that the population distribution data accurately reflect year-round habitat quality for moose.

FIGURE 19.2: THE RELATIONSHIP OF ANNUAL MOOSE DISTRIBUTION AND HABITAT QUALITY[1]



[1] For the purpose of this paper, only the "Best" moose habitat is identified.

RESULTS

Success with the Spreadsheet

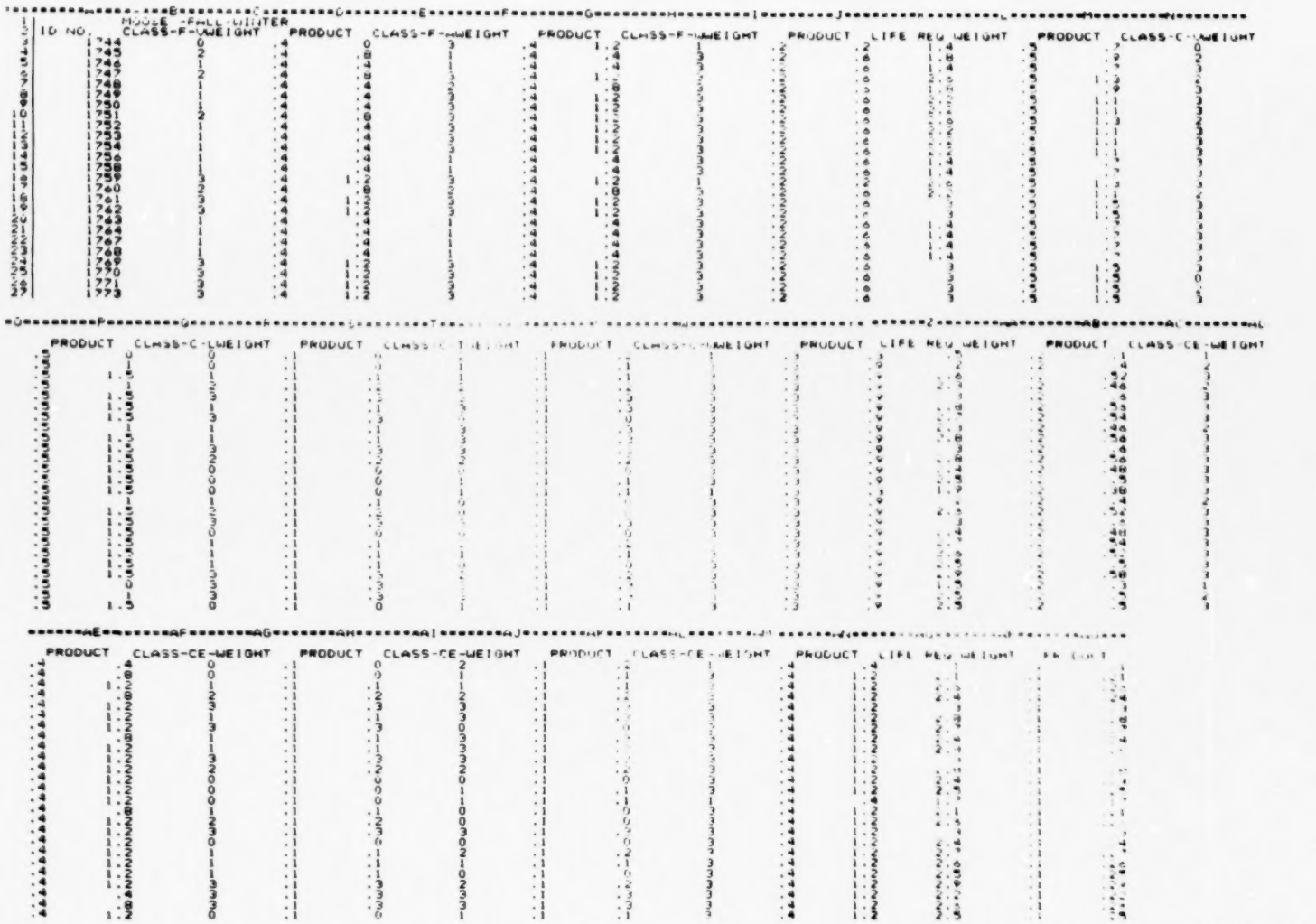
Memory limitations forced us to divide the model into seasonal sub-models (i.e., spring/summer and fall/winter), and to create six seasonal sub-model data files (i.e., 12 data files for all seasons) in order to work with all of the data. This is a major inconvenience resulting from limited RAM. Current habitat suitability values were generated for the spring/summer season and then incorporated into the fall/winter spreadsheet to facilitate circulation of an annual current habitat suitability.

TABLE 19.4: AN EXAMPLE OF THE FORMULAS AND THE SPLIT SCREEN FUNCTION OF THE SPREADSHEET PROGRAM USED TO EVALUATE MOOSE HABITAT

File: MOOSE

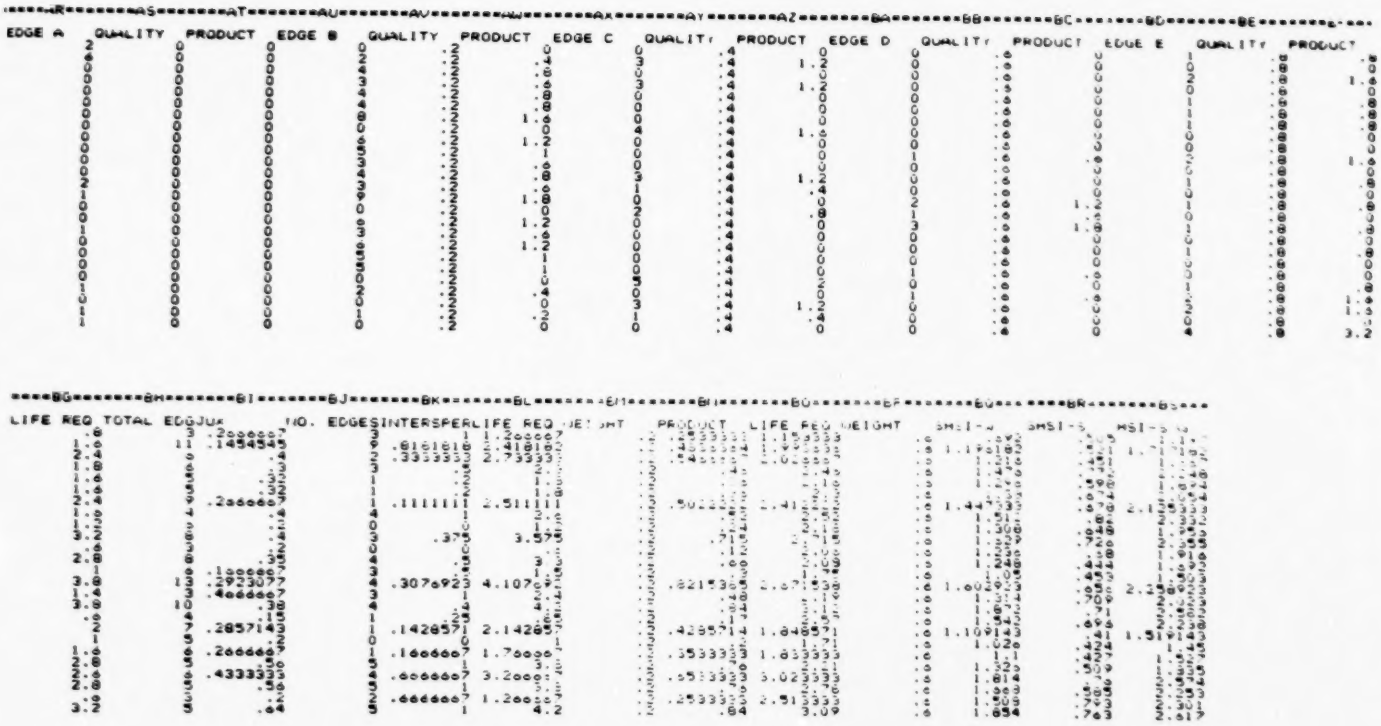
--A--	--B--	--C--	--D--	--E--	BR	BS
1/	MOOSE-FALL/WINTER					
2/ID NO.	CLASS-F-V	WEIGHT	PRODUCT	CLASS-F-A	SHSI-S	HSI-S/W
3/1744	0	.4	+B3*C3	3	.505	+BQ3+BR3
4/1745	2	.4	+B4*C4	1	.521	+BQ4+BR4
5/1746	1	.4	+B5*C5	1	.451	+BQ5+BR5
6/1747	2	.4	+B6*C6	3	.772	+BQ6+BR6
7/1748	1	.4	+B7*C7	2	.598	+BQ7+BR7
8/1749	1	.4	+B8*C8	3	.674	+BQ8+BR8
9/1750	1	.4	+B9*C9	3	.678	+BQ9+BR9
10/1751	2	.4	+B10*C10	3	.82	+BQ10+BR10
11/1752	1	.4	+B11*C11	3	.648	+BQ11+BR11
12/1753	1	.4	+B12*C12	3	.726	+BQ12+BR12
13/1754	1	.4	+B13*C13	3	.68	+BQ13+BR13
14/1756	1	.4	+B14*C14	1	.444	+BQ14+BR14
15/1758	1	.4	+B15*c15	1	.453	+BQ15+BR15
16/1759	3	.4	+B16*C16	3	.656	+BQ16+BR16
17/1760	2	.4	+B17*C17	2	.709	+BQ17+BR17
18/1761	3	.4	+B18*C18	3	.71	+BQ18+BR18

TABLE 19.5: AN EXAMPLE OF THE MOOSE HABITAT EVALUATION MODEL IN A SPREADSHEET FORMAT



Continued

TABLE 19.5 (Cont.)



Current Habitat Suitability Values and Validation

The current habitat suitability values were plotted for each of the land units in the study area (Figure 19.2). The multiyear distribution data for moose were then plotted over the land units (Figure 19.2). Although this evaluation model is preliminary, and subject to modification, there is an obvious positive relationship between most of the areas which were rated as the "Best" habitat and the observed distribution of moose. We did not identify any "Inadequate" land units. "Inadequate" land units do exist, however, as reflected in some of the extreme features of the area (e.g., mountainous terrain). Therefore, we combined the "Poor" and the "Inadequate" rankings; thus, the suitability of the land units in the study area were identified according to a three point scale (Best, Moderate, and Poor-Inadequate).

DISCUSSION

The Spreadsheet

As a general principle, the simpler the technique employed, the more useful or generally applicable the model (Bunnell, 1974). Many of the advantages of using a spreadsheet to develop and implement models revolve around this principle. The user-friendly nature of the software, whereby successful development and implementation of a model using the spreadsheet program does not depend on a computer programmer, is a major advantage. This commercial package is very forgiving.

The spreadsheet program retains a copy function which facilitates rapid deployment of similar or exact copies of desired formulas (Silvert, 1983b). The edit function, which enhances the iterative interaction between the modeller and the computer (Silvert, 1983b), provides outstanding flexibility. In addition, the flexibility in data manipulation and viewing functions (e.g., split screen) are useful. Eedy et al. (1986) found the spreadsheet approach to modelling useful because of the portability of the model to other geographic locations. Another advantage is that the effects of changes made to any of the model parameters can be determined immediately (Silvert, 1983b).

The type of microcomputer used, and the amount of available memory, can limit the modeller's ability to construct and run large models. This limitation is particularly annoying, because even though our model is simple, it is lengthy and requires a large database. It is very important that modellers determine their data storage requirements prior to selecting a computer to conduct their work. In addition, spreadsheet programs offer a limited selection of mathematical functions. For the most part, the majority of models could be constructed using the simple mathematical functions provided; however, the modeller will have to write a new program or access a different program should complex mathematical functions be required.

The Model - Methodology

Resource managers require land survey techniques which present landscape areas as dynamic ecosystems comprising interrelated physical and biological components (Canadian Committee on Ecological Land Classification [CCELC], 1985). The proponents of many resource surveys in the past have either ignored wildlife completely, or have incorporated wildlife as an afterthought, following the completion of the classification phase of the survey (Bastedo and Theberge, 1983; CCELC, 1985; Parks Canada, 1977). For example, some resource surveys include general wildlife information (e.g., species lists), but fail to provide information on population dynamics and/or the environmental factors which comprise wildlife habitat and influence the distribution and abundance of wildlife in relation to habitat. Some of the

reasons for this include:

1. many wildlife species are highly mobile and utilize a variety of landscapes in space and time,
2. wildlife populations can fluctuate widely over time,
3. wildlife are relatively difficult to observe,
4. relatively little is known of wildlife-habitat interactions, and
5. habitat features are subject to change.

On the other hand, Hoekstra (1986) argues that researchers have failed to extrapolate a large volume of existing data describing wildlife habitat requirements to land management planning programs.

East et al. (1977, p. 215) wrote that "... difficulties arise in that different faunal groups have varying mobility, perceive the environment at multiple levels of resolution, and have behavior patterns that alter seasonally". Rowe (1980) suggests that biological (in this case wildlife) phenomena should be checked against physiographic features to ensure that the boundaries of the land units are significant. This concept is particularly relevant when considering the development and application of models which assist resource managers in their efforts to describe land units. Few studies completed to date address this concept. Wildlife managers have not developed techniques designed to interpret wildlife distribution and abundance within the context of ecological data stored in the ELC system database or other databases available to them. In many cases, population surveys have not been designed according to a stratification and sampling of variable habitat types and classes of habitat quality (Stelfox, 1986). Resource managers must evaluate population and habitat data in order to identify the most suitable habitat model variables. This project represents one small effort to improve our ability to use an existing database.

The rankings and weightings used in this exercise are entirely subjective, and are based upon the modeller's interpretation of the relevant literature, and experience with the species and the study area. In this context, it is crucial that all subjective aspects of the decision-making process be explicit (Matthews, 1975).

It is important to note that rankings lack a standard scale with common origin and known interval. Therefore, comparisons of rankings between independent resource managers is meaningless. However, this technique is useful for the individual resource manager who makes all of the assessments himself (Sinden and Worrell, 1979) or for an integrated team of biologists (Mule, 1982) striving to generate consistent habitat rankings. It is possible that consensus could be reached by employing the integrated team approach. Despite this limitation, a large number of researchers continue to use ranking techniques primarily because of the speed with which this technique can be employed, the ease (and hence reduced error margin) of application by the user and comprehension by the reader, and the similarity between ranking and other methods (Sinden and Worrell, 1979). An important point to remember is that this system is not designed to provide an absolute value of each land unit as moose habitat. It is intended to provide a relative ranking in comparison with other land units (Tans, 1974). Even though the ranking system aids in the identification and evaluation of moose habitat, it is not the only decision-making technique available, and should not be used or interpreted as an absolute.

The subjective nature of parts of the scoring system means that little reliance can be placed on small differences in score between one land unit and another (Ogle, 1981). In fact, the model has a tendency to smooth out the values through an averaging procedure. The more factors involved in evaluating an

area the more averaging there will be, thus masking obvious qualities, including deficiencies (Tans, 1974). This results in a reduction in the number of land units designated as "Best" and "Inadequate", and an increase in the number of land units designated as "Poor" or "Moderate" habitat. Presently, two alternative approaches to reduce or eliminate this problem are being examined (Stelfox, 1986), and include restructuring of the use of, and value of, the numbers, and development of a principle which explicitly defines those compensatory mechanisms which are legitimate (e.g., can the absence of one type of vegetation be compensated for by the presence of another) and those which are not legitimate. If it is not possible to apply a compensatory mechanism, then the program should be instructed to assign a value of 0 (Inadequate) or the value of the most limiting variable as the current habitat suitability.

Statistical analyses can be employed to reduce the number of environmental variables used to measure the suitability of an area for wildlife habitat. Correlation analysis could be used to identify those environmental variables which are related to the distribution of wildlife. Multidimensional scaling could be used to reduce the number of correlated variables employed in the model.

The Model - Results

An ideal measure of a site's importance as moose habitat is the number of moose days. However, collection of this type of data is difficult and expensive; few wildlife managers can afford the time and money required to collect this information in support of a decision-making process. It is not available for most areas in the Northwest Territories. Therefore, we have pursued the development of a land-based habitat evaluation model, which requires a minimal amount of wildlife data. Within the context of land management, which includes allocation, this approach to modelling is very useful because it is land based, and it allows the manager to include wildlife data. The use of explicitly documented models provides a record of the evaluation and a sound basis for recommendations.

SUMMARY AND RECOMMENDATIONS

The spreadsheet format can be effectively employed to develop wildlife habitat evaluation models. However, it is strongly recommended that modellers determine their data storage and matrix manipulation requirements prior to selecting a computer and the associated software to conduct the work.

The results presented in this paper are preliminary and should be interpreted with this fact in mind. We make the following recommendations to improve this modelling procedure.

1. The limiting factors, cumulative relationships, and compensatory relationships should be explicitly identified and incorporated into the model.
2. The averaging effect should be minimized or eliminated.
3. The environmental variables used to describe moose habitat should be confirmed through statistical analyses (e.g., correlation analysis and multidimensional scaling).
4. A measure of the internal homogeneity of the land units should be developed and incorporated into the model.
5. The different techniques which could be used to determine interspersion and juxtaposition should be reviewed, tested, and validated in the model.
6. A measure of confidence in the wildlife population and distribution data is necessary. This measure should be incorporated into the model.
7. Predictions must be validated against distribution and abundance data. It is recommended that a technique to employ sensitivity analyses to determine the overall usefulness of the model be developed.

A useful evaluation technique is one which employs the fewest criteria, but which most

accurately reflects an area's value. The purpose of the model is to provide the resource manager with information about the quality of the area as habitat for the species of concern. The key is to develop or adopt, and employ a modelling technique which is time and cost effective, accurate, and employs existing information. Only then will managers feel comfortable enough to use the model as a decision-making tool.

NOTES

1. P.A. Gray is currently with the Ontario Ministry of Natural Resources, Toronto, and J. Keith is currently with the Delta Waterfowl and Wetlands Research Station, Georgetown.

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20

APPLICATION OF GIS TECHNOLOGY TO THE HEP HABITAT LAYERS MODEL

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ABSTRACT

The purpose of this project was to integrate wildlife habitat layer components into ecological land classification for planning purposes. The study used existing information to generate habitat layer index (HLI) data necessary to evaluate the application of the HLI model in classification of wildlife habitat over relatively large areas, using remote sensing and geographic information system (GIS) computer techniques. Methods included use of the United States Fish and Wildlife Habitat Evaluation Procedures' (HEP) habitat layers model (United States Fish and Wildlife Service, 1980) in interpretation and classification of medium-scale (1:80,000) colour-infrared photos, large-scale (1:12,000) colour photos, and large-scale (1:5,000) black-and-white orthophotos for application to the Environmental Systems Research Institute's (ESRI) ARC/INFO software (Version 3.2).

Habitat in the approximately 1,450 ha Clay Brook watershed in the upper Mad River Valley in central Vermont was classified according to the HLI model (modified for aerial photo interpretation) and according to a modified United States Geological Survey land use/cover classification system (University of Michigan) used in the Vermont GIS Program. A low HLI value was found for the Clay Brook watershed as a whole (0.38), indicating that 38 per cent of the maximum potential vertical structural diversity was present. The value does not indicate presence of absence of particular wildlife species. However, for future study, linkage of the model with data such as bird species diversity might prove useful in this regard.

If possible, future ground referencing should be done to check the accuracy of the HLI cover type classification. In this study, only present habitat conditions in the Clay Brook watershed were mapped with ARC/INFO. Future applications of the HLI model to ARC/INFO should include refinement of model criteria for investigation of the impacts of secondary housing developments on wildlife habitat in the Clay Brook watershed. The HLI model is particularly suitable for the early stages of development planning. The level of habitat diversity desired will depend on planning and/or management needs.

SCOPE OF PROJECT

The project was an expansion of ongoing studies in the application of ecological principles to large-scale comprehensive forest land planning. The umbrella research program at the University of Vermont (Hendrix, 1984) accommodates three hierarchical levels of research:

1. ecological land classification,
2. transactions between the components of the ecological land classification system, and
3. the movement of energy and materials into and out of a geographically defined ecosystem. This study addresses the first level of research in terms of wildlife planning with an applied, non-theoretical multiresource orientation.

The existing database for the ongoing research in the Clay Brook watershed (Sugarbush Ski Area) in the Mad River Valley (Figure 20.1) includes land use, slope, stream order and class, highways and roads and their order and class, highways and roads and their surface types, well locations, elevations, and soils. No data yet have been acquired to include faunal characteristics in the classification models being developed in the first level of research. The 1974 Forest and Rangeland Renewable Resources Planning Act of the United States Congress mandates management for biological diversity of wildlife as one of the multiple resources of federal forest lands. Large-scale land-use planning is in progress for the United States Forest Service land under the National Forest Management Act of 1976 (Hendrix, 1984). Wildlife resource data are an important aspect of multiple resource planning.

This study used a habitat evaluation model in creating a data layer of classified wildlife habitat. This was done to facilitate the inclusion of wildlife resources in ecologically based planning and impact assessment in an area currently under intense development pressure. Future research will be left to address problems of guild development for species selection (Block et al., 1984; DeGraaf and Chadwick, 1984; Mannan et al., 1984; Roberts and O'Neil, 1985) in modelling and prediction of project impacts (Hawkes et al., 1983) on wildlife habitat and populations. This study was restricted to application of GIS technology to the United States Fish and Wildlife Service Habitat Evaluation Procedures' (HEP) habitat layers model.

THE HEP SYSTEM

The HEP "accounting procedure" (Schamberger and Krohn, 1982) is based on habitat quantity measures combined with a habitat suitability index (HSI) to determine habitat values for species or guilds in question:

Habitat Area x HSI = Habitat Units (HUs).

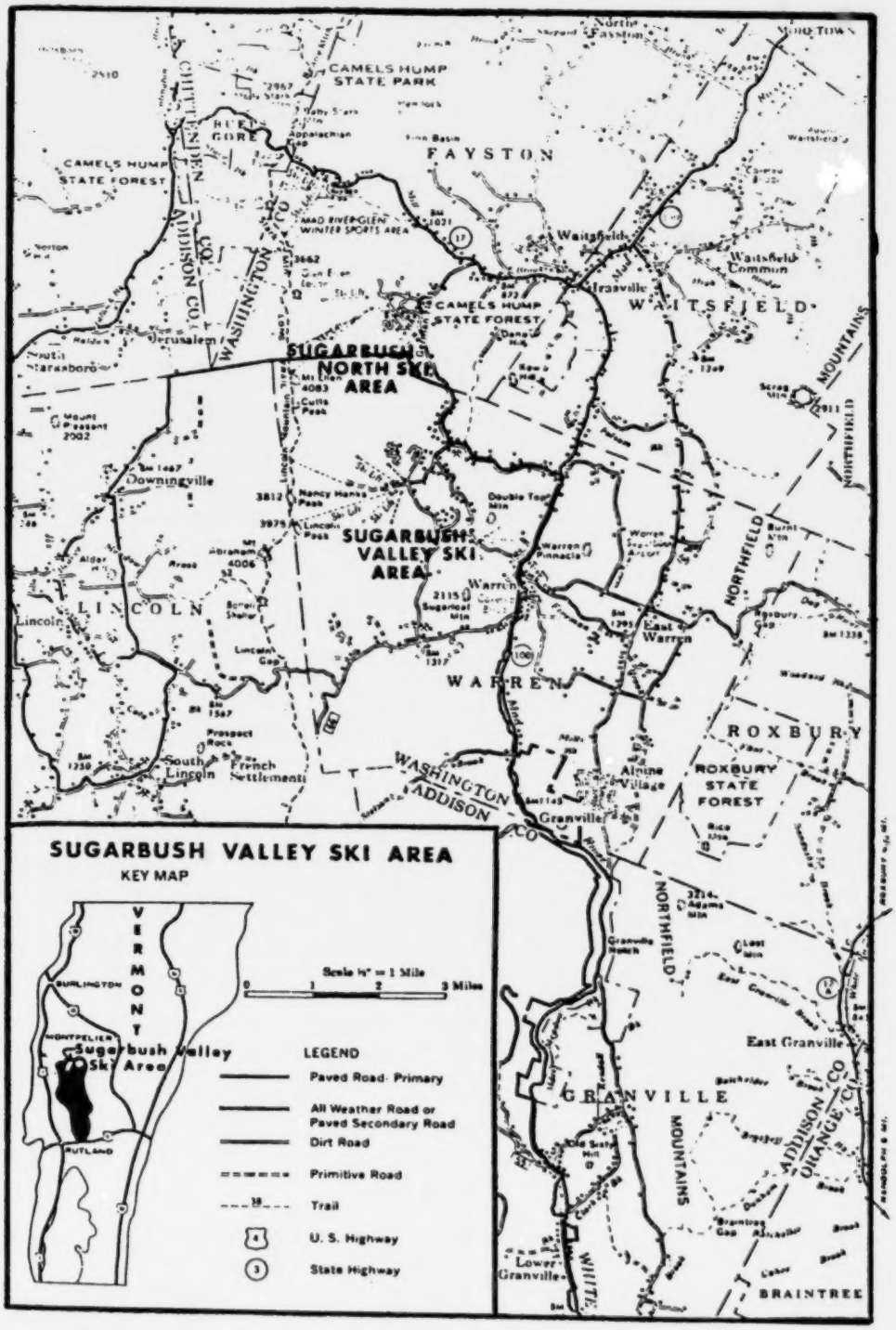
HSIs can be determined by several documented methods that include models of quantified evaluation criteria. HSI is a value between 0.0 and 1.0. Assuming HSI is positively correlated to habitat carrying capacity, 1.0 is the maximum habitat quantity in a given area. In an evaluation, HU data are generated for each species, life requisite, life stage or guild in question (Schamberger and Krohn, 1982). Study objectives and evaluation species must be very carefully chosen. HEP "accounting" is computerized to aid in calculating HUs and to perform other data manipulations for baseline and impact studies.

For purposes of this study (creation of a database for multiresource planning), ecological community-based HSI models were most appropriate. Single-species models require interspecific extrapolation of data if the management goal is species diversity, or if management indicator species are used. HEP evaluation species can be selected for socio-political, ecological, or economic reasons. Roberts and O'Neil (1985) note that HEP is species-based but that it can focus on either wildlife or vegetation. This is desirable, but

> many biologists feel that because HEP is a "wildlife" habitat evaluation method, the emphasis should be on the animal community with the plant community given only secondary consideration (Roberts and O'Neil, 1985, p. 5).

This would be true of single-resource planning such as that for a wildlife refuge, but would be unnecessarily restrictive for multiresource planning. These problems and difficulty with guild development prompted the choice of

FIGURE 20.1: CLAY BROOK STUDY AREA (SUGARBUSH VALLEY SKI AREA)



the habitat layers model (Short and Williamson, 1984) for this study over the Arizona guild HSI model (Short, 1984), the two community-based HSI models currently available. "The comprehensive study requiring broad ecological perspective has been particularly troublesome for many HEP planners" (Roberts and O'Neil, 1985, p. 17). This study may be no exception, but it will provide feedback on the application of the habitat layers model to planning integrated with ecological land-use classification and GIS technology.

GIS TECHNOLOGY

Gates and Heil (1980, p. 105) point out that "GIS technology does not represent a single technological approach nor is it a homogeneous technological arena". GIS technology uses spatial data which are useful in creating, designing, and evaluating land-use plans, impact analyses capability/suitability analyses, etc. Spatial data combine both a measurement of an attribute and the geographic location of that attribute and are usually organized in a map framework (Gates and Heil, 1980). Basically a GIS database must be able to produce derived data and information including mapped displays of geographic data based on original data. Recent advances in the merging of computer graphics and database management have made GIS technology practical and more cost-effective in application (Erdle and Jordan, 1984). However "the true test of any GIS is the extent to which it gets used to deal with problems based on spatial data" (Gates and Heil, 1980, p. 115).

Erdle and Jordan (1984) describe building a GIS database for inventory-related data, as applied in the New Brunswick forest protection program. Geographic location data are collected in digital form by identifying lines on a map (arcs), which are defined by coordinates of starting and ending points (nodes) and changes in direction (vertices). Measurement of data is done through digitizing, which may be manual or automated scanning, in which coordinate number pairs of locational information are stored in a computer. Once all arcs have been digitized they are edited electronically to remove errors, and are stored unassociated and unstructured. They are then assembled electronically in polygons, lines, or points to represent spatial relationships. Attribute data, acquired by photo interpretation and/or ground sampling, are then coded and entered via keyboard into the computer. The unique identification code of the attribute data is the link between a descriptive attribute data and its geographic location.

Database use involves amalgamation, modelling, and aggregation or map merging, reclassification, overlay, data search, and updating (Erdle and Jordan, 1984). Some part of the basic database is reformatted to create new information. Maps may be combined or windowed (focussed on a subset of a geographic area). Data can then be reclassified to infer new characteristics about a given feature, such as susceptibility to spruce budworm. Data can be aggregated in an overlay procedure that creates new variables. The database can also be searched for a particular geographic location with given attributes and updated, replacing old data without aggregating. Tabular summaries from a GIS provide quantitative data whereas computerized maps show the spatial data distribution. The real power of GIS technology is the opportunity to analyse information inherent in map structure that is not necessarily displayed on the map (Erdle and Jordan, 1984).

The Vermont GIS

In 1979, the University of Vermont began to consider the acquisition of a GIS for use in natural resource planning with emphasis on problems of developing growth in rural areas. In 1980, the University of Vermont bought GIS software and hardware. Software includes both grid and polygon-based systems (Hendrix and Newton, 1984).

Data entry methods include manual digitizing, raster scanning followed by vector conversion, incorporation of existing

> computer formatted information and digital ... satellite imagery. (Smith and Hendrix, 1985, p. 1).

Hardware includes a VAX 11/750 minicomputer, a Talos digitizing tablet, a four-pen COMPLOT drum plotter, and a Tektronix 4112A graphics terminal.

In 1981, a project was begun to demonstrate the use of GIS technology in rural natural resource planning in Vermont (Hendrix and Newton, 1984). Initial data layers formed the basis for derivation of others. Ultimately both the original data layers and layers derived from them will be available for analysis (Figure 20.2). Aspect, elevation, and slope were derived from topography; stream order and water quality, and road type and surface information are available as well (Hendrix and Newton, 1984). The sources of the data layers are shown in Table 20.1. Applications of the GIS have since been made in timber management, highway corridor alignment, agricultural land assessment, zoning changes, and visual resource management (Hendrix and Newton, 1984). In 1983, the University and the United States Soil Conservation Service (SCS) entered into a cooperative agreement for data entry into a statewide GIS database (Smith and Hendrix, 1985). Other applications recently made include

> watershed management, groundwater modeling, evaluation of resource sampling and measurement procedures, and development of ecologically based forest land planning models (Hendrix and Newton, 1984, p. 6).

The GIS is viewed as an important part of natural resources management in a rural state in which the natural resource base is extremely economically important (Hendrix and Newton, 1984).

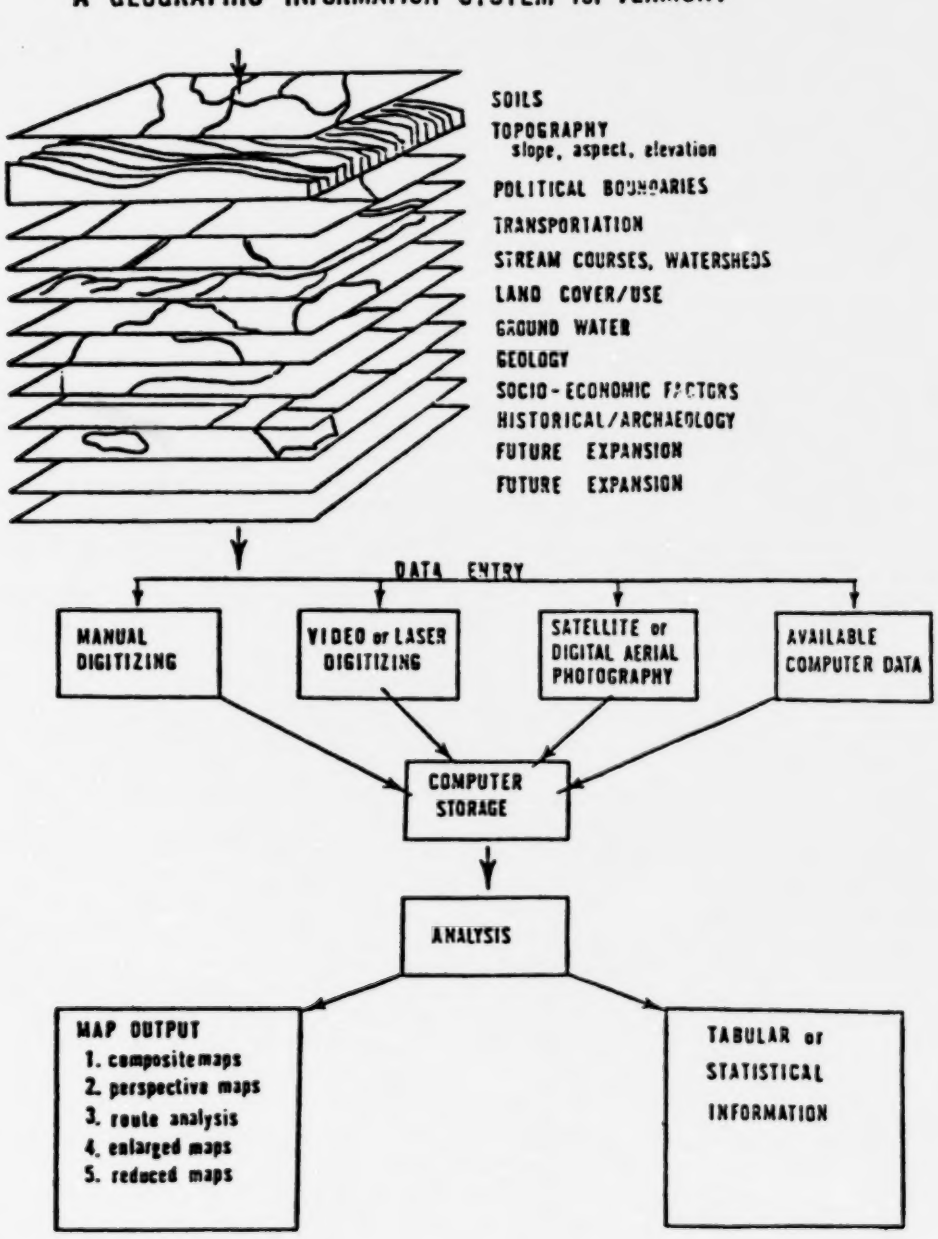
TABLE 20.1: DATA LAYERS AND SOURCES

DATA LAYER	SOURCE
Geology	Mad River Valley Growth Study Plan, Central Vermont Regional Planning
Highways and Roads	Vermont Department of Transportation
Land Use	University of Vermont School of Natural Resources, Remote Sensing Applications Program
Streams and Rivers	United States Geological Survey (USGS)
Soils	SCS
Topography	USGS
Well Locations	Vermont Water Resources
Wetlands	National Wetland Inventory
Zoning	Mad River Valley Growth Study Plan

GIS AND HABITAT INVENTORY

Mayer (1984) states that a GIS used for wildlife habitat inventories should be able to handle vector data (line segments created from polygon data), raster data (in cellular or point format), tabular/textual data, and digitized wildlife species occurrence data (vector data) being processed to produce qualitative and quantitative assessments. This is the type of approach taken in some of the existing applications of GIS technology to wildlife inventories for planning and impact assessment, and species/habitat relationships. One example of a state-wide application is the Colorado Division of Wildlife's Wildlife Resource Information System, which includes an inventory database and a GIS to enter, store, retrieve, and analyse population/distribution information (Shrupp, 1982). Two habitat identification approaches are used. In one, data are structured to display field-observed seasonal,

FIGURE 20.2: CONCEPTUAL CONFIGURATION OF THE DATA SYSTEM (VERMONT GIS PROGRAM, UNIVERSITY OF VERMONT)



functional, and distributional variations in species use of habitats, with mapped areas grouped categorically (Shrupp, 1982, p. 168). The other approach models separate habitat components such as food, water, and cover, to predict species distribution. This is made possible by GIS capability to display iteratively and analyse interrelationships of multiple habitat factors. Future use will probably include a hybrid of the two approaches (Shrupp, 1982). Thus GIS technology can help to expand the "snapshot-in-time" offered by both qualitative and multivariate statistical approaches to habitat evaluation (such as HEP) for modelling of resources management alternatives to gauge impacts on wildlife habitat and populations (Patch, 1984).

PROCEDURES

Description of Study Area

Hendrix and Newton (1984) have described the Mad River Valley research area. The upper valley is of particular interest, an area of 21,016 ha in the towns of Fayston, Waitsfield, and Warren. The Clay Brook watershed in the town of Warren (Figure 20.1) was the study area of interest here, an area of about 1,378 ha. The land use/cover is a mixture of forested, agricultural, and developed areas, in a mixture of private, local, state, and federal ownership. The topography includes flat floodplain areas in the river valley to very steep slopes rising to the crest of the Green Mountains. The area's population is less than 3,000, with an economy based on agriculture, forestry, light manufacturing and winter sports. The area is experiencing increased development pressure because of expansion of the major winter sports facility. Jobs and second homes are expected to increase, along with pressures to supply additional municipal services. Impacts on the natural resource base will also occur, with far-reaching implications for the future of the valley.

Preliminary Data Collection

The data were collected in four major steps:

1. delineation of the existing classified and mapped polygons of the Clay Brook watershed on USGS 1:24,000 topographic base maps via 1:80,000 colour-infrared photos,
2. preparation of a more detailed base map from 1:5,000 black-and-white orthophotos for digitization into the GIS program ARC,
3. gathering of habitat data via interpretation of 1:12,000 colour photos for attribute tables to be entered into the GIS program INFO as Level IV HLI classification data, and
4. output of ARC/INFO maps showing integration of wildlife habitat data with ecological land use/cover classification.

The study used existing information and generated new data when necessary. The study area was classified with the Michigan system (based on the USGS system) which was carried to Level III for forest land and some residential areas and to Level IV for other residential and all urban areas. New data were needed for areas lacking Level IV classification and for all areas without Level IV habitat data.

HLI Data Collection

The data collected were determined by the inputs to the HEP habitat layers model (Short, 1984). The model is based on the assumption that non-fish vertebrate wildlife species use habitat resources along a vertical dimension that can be represented as habitat layers. In this model, cover types are considered to be combinations of these habitat layers, or volumes of space at different levels above or below air-land or air-water surface interfaces. A layer of habitat is considered to be present if it occurs in a polygon above a given threshold. This concept of cover types is different from the

traditional concept of horizontal vegetative cover. Cover type is here defined as any combination of somewhat arbitrarily defined vertical volumes of space. These volumes are then mapped as areas enclosed by polygons and provide data to classify the polygons.

The criteria for defining each habitat layer in this study were derived from several sources (Table 20.2). The habitat layer criteria used by Short (1984) were assumed and not tested, but were modified for use with photo interpretation (except the stream buffer zone). The basic habitat layer index equation (Short, 1984) is as follows:

$$HLI = \frac{(\text{number of layers actually present}) \times (\text{area of each actual layer})}{(\text{number of layers potentially present}) \times (\text{area of each potential layer})}.$$

Thus the numerator is the product of the number of layers and the area of each layer actually present. The denominator is the product of the same in terms of potential occurrence in the most structurally complex cover type that could theoretically occur in the study area. The equation was modified for use in this study by changing the coefficients of the denominator from the example used by Short (1984), which was developed for use in the western United States. An HLI value was calculated for the entire Clay Brook watershed. For descriptive mapping purposes, the individual HLI cover types for each polygon were keypunched into INFO. For future modelling purposes, basic data such as tree height will also be added to the INFO database.

The data and collection methods for HLI photo interpretation are shown in Table 20.3. These methods were based on modification of the HLI discussed above and standard methods found in Avery (1978). Tree height in this study was considered to be total height and not merchantable height, because the former was used to distinguish between overstory and shrub layers for HLI calculation. Areas of previously classified polygons and an arbitrarily defined stream buffer zone (one grid cell wide) were also required to calculate the HLI. Otherwise, streams as defined by mapping rules discussed below would appear only as lines in ARC/INFO maps.

Classification and Mapping Rules

Consistency in classification and mapping is ensured by abiding by explicit rules developed from the data and materials used (i.e., study needs and mapping conventions). The previously classified polygons were classified according to a common method known as dominant land use (DLU). Here an area's dominant feature is assigned as the classification category based on area measurements (Table 20.4). The rules used in this study were taken from those used for the University of Vermont demonstration project in the Mad River Valley. They were used to classify polygons according to Level IV HLI data and then to map the polygons at 1:5,000 for a detailed base map. All forest and agricultural areas greater than 0.4 ha were mapped. This was done so that areas straddling the border of the watershed would be mapped and no "holes" would be created for later ARC digitization. All urban, residential, and recreational areas were mapped as found on the 1:24,000 mylar overlay map of the town of Warren made for the demonstration project. Linear features such as streams and roads were mapped as shown on the USGS topographic maps. Ski trails that were at least 15.2 m wide were mapped as shown on the orthophotos. This criterion was chosen for ease of digitization (i.e., having fewer small polygons due to narrow ski trails).

HLI Sampling by Photo Interpretation

For Level IV HLI data, a stratified random preliminary sample was done to determine variability in the parameters measured and the six land use/cover classes: forest, agricultural, urban, residential, recreational and winter sports areas. These classes were chosen because of the planning orientation of this study, thus ensuring that human use areas were not lost in sampling because of their relatively small areas as compared to forest land. Stratification also reduces sampling error if strata are defined so they

TABLE 20.2: MODIFICATION OF THE HEP HABITAT LAYERS MODEL FOR USE WITH PHOTO INTERPRETATION

LAYER	VARIABLE MEASURED	CRITERIA	CRITERION SOURCE
Overstory	Crown closure	More than 5% cover	Short, 1984
	Crown diameter	1.5 m classes	Avery, 1978
	Tree height	More than 7.6 m	Short, 1984
Shrub Layer	Crown closure	More than 5% cover	Short, 1984
	Crown diameter	1.5 m classes	Avery, 1978
	Tree height	More than 7.6 m	Short, 1984
Herbaceous Layer	Crown closure	More than 5% treed	Short, 1984
Standing Water	Area	No outlet	USGS topo. map
Running Water	Area	Outlet(s)	USGS topo. map
Terrestrial Surface	Area	Watershed boundary	USGS topo. map

TABLE 20.3: DATA AND COLLECTION METHODS FOR PHOTO INTERPRETATION OF CLAY BROOK WATERSHED

HABITAT LAYER	ATTRIBUTE VARIABLE	METHOD OF MEASUREMENT
Overstory	Crown closure	Density scale
	Crown diameter	Crown wedge or dot scale
	Tree height	Parallax bar
Shrub story	Crown closure	Density scale
	Crown diameter	Crown wedge
	Tree height	Parallax bar
Herbaceous story	Crown closure	Density scale
Standing water	Area of water body	Dot grid (16 dots/in^2)
Running water	Area of buffer zone	Dot grid
Terrestrial surface	Area of previously classified polygon	Dot grid

TABLE 20.4: EXAMPLE OF CLASSIFICATION RULES FOR PRIOR-CLASSIFIED POLYGONS

LEVEL I	LEVEL II	LEVEL III	CRITERION
4 Forest	41 Broadleaved forest	411 Upland hardwoods	More than 70% area covered
	42 Coniferous forest	421 Upland conifers	More than 70% area covered
	43 Mixed forest	431 Hardwoods predominate	Neither of above and more than 50% area covered by hardwoods
		434 Softwoods predominate	Neither of above and more than 50% area covered by softwoods

contain relatively uniform sampling units and each unit is sampled individually (Myers and Shelton, 1980).

Stratified random sampling was then set up via random numbers on a 16 dot/in^2 (16 dot/2.54 cm^2) grid for point sampling within all previously-classified polygons after a sample size for each stratum was determined (Table 20.5). Sample size can be determined for the accuracy level desired (Myers and Shelton, 1980), usually at the 90-95 per cent level. Point sampling allowed complete coverage of each polygon for classification accuracy and ARC/INFO modelling. Point samples are often used to represent area data (Myers and Shelton, 1980). Randomization reduced problems of systematic bias due to existing topography (Myers and Shelton, 1980) with the north-south trending mountains and generally eastward streamflow found in the study area.

Interpretation techniques can affect land-use mapping accuracy. Best results with the USGS system and a grid cell matrix are not always obtained with the smallest cell size and techniques less complex than stratified systematic unaligned sampling can produce more accurate data (Henderson, 1980). Two habitat evaluation studies that include testing classification accuracy, report using confidence intervals of 95 per cent (Fine et al., 1978) and 90 per cent (Todd et al., 1980). Similar levels of accuracy testing were attempted in this study. The DLU method of classification used in this study was an areal sample and was previously used in the Vermont demonstration project to generate previously-classified polygons. It was used again to generate Level IV HLI data since point sampling was used to represent areal data at Level IV. Random placement of grid cells over the study area photos will be attempted here. However, Henderson (1980) found that placement is a non-random decision in some cases, and the optimum interpretation technique varied inconsistently among site and category tested.

CONCLUSION

Preliminary analysis indicates that the habitat layers model is particularly applicable to the entry stages of development planning (Short, 1984). However, the model should be modified for use of remote sensing methods when ground sampling is impractical. This is useful for low-resolution planning with

TABLE 20.5: STRATIFICATION OF PRIOR-CLASSIFIED POLYGONS BY LAND USE/COVER TYPE WITH APPROXIMATE AREAS AND SAMPLE SIZE DETERMINATION FOR CLAY BROOK WATERSHED

STRATUM	CLASSIFICATION	AREA (HA)	SAMPLE SIZE DETERMINATION
Forest	411 Upland hardwoods	507.7	Sample size formula[1]
	421 Upland conifers	45.9	
	431 Mixed woods, mostly hardwoods	185.7	
	434 Mixed woods, mostly softwoods	387.5	
Agricultural	2129 Other pasture	7.6	As mapped at 1:5,000
Urban	1167 Motel	14.4	Sample size formula
	1241 Central business district	1.1	
	127 Indoor recreation (public)	1.5	
	1425 Mass transport	3.8	
	1448 Public parking	3.9	
	1466 Water treatment	4.0	
Residential	112 Multifamily	10.1	Sample size formula
	1121 High-density apartments	14.3	
	113 Single family	47.7	
Recreational	1931 Landscaped/ aesthetic	1.7	Sample size formula
	1933 Ski trails	92.4	
	1933 Golf course	46.1	
Water	52 Buffer zone	39.2	As mapped at 1:5,000
	52 Lake/pond	0.4	

[1] Giles (1971)

"site-species methodology" (Coulombe, 1978) or "moderate" to "large" project areas (405-405,000 ha) (Mayer 1984).

Possible wildlife planning needs due to development in the Clay Brook watershed were identified by consulting with the Central Vermont Region Planning Commission, the Green Mountain National Forest, and the town of Warren. Detailed conclusions about application of the habitat layers model to integration of wildlife habitat into ecological land use/cover classification vis GIS technology were drawn.

The habitat layers model emphasizes the vertical structural diversity of a habitat and provides a measure of such diversity (Short, 1984). The level of diversity desired will depend on planning and/or management goals determined by habitat area mitigation and compensation for development-related changes. Low HSI values such as that found for the Clay Brook watershed as a whole (0.38) indicate that 38 per cent of the maximum potential structural diversity is present in the watershed habitat. This value does not indicate presence or absence of particular wildlife species. However, for future study linkage of the model with data such as bird species, diversity might prove useful in this regard. Examples of ARC/INFO modelling and mapping with the HLI data will be developed showing integration of wildlife habitat data with ecological land-use classification.

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